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LB/TS Optical Blast Measurement

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13. ABSTRACT *(Maximum 200 words)*

A laser beam system for measuring airshock time of arrival (TOA) was designed and developed for use in the Defense Special Weapons Agency's (DSWA's) Large Blast and Thermal Simulator (LB/TS). A limited array of four laser beams was installed and exercised in three test shots in LB/TS. The shock TOA was measured with high precision ($\pm$ 0.5 μs). The shock overpressure was computed from the shock TOA measurements and compared with measurements using pressure rakes. The laser system proved highly reliable and required little maintenance and preparation time for each test. A multiple beam array can be used to provide not only accurate measurements of shock wave TOA but also accurate shock front pressure.

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SUMMARY

An optical system using milliwatt laser beams was designed and developed for use in the Defense Special Weapons Agency's (DSWA's) Large Blast and Thermal Simulator (LB/TS) to measure airblast shock front arrival. The thin laser beams are directed across the blast tunnel to optical receivers which transmit the light through fiber-optic cables to the facility recording room. When the air shock front arrives at the beam station, the air density discontinuity at the shock front diffracts the laser beam away from the beam receiver optics, thus measuring time of arrival (TOA) of the shock front. In addition, a pair of tandem beams is used to measure the shock speed between the beams, from which the overpressure of the shock front is calculated.

Beam arrays for measurements at the facility's test section, just downstream of the blast driver tube, and at intermediate locations were designed. These arrays include up to 17 laser beams. A limited array of two beam pairs was installed in the LB/TS tunnel at a station ~14 m downsteam of the driver tube wall. These beams were used during three test shots employing a single driver tube.

Results of the laser beam measurements gave shock TOA within ±0.5 μs. The horizontal velocity of the shockwave was measured with high accuracy and very reliably, with little preparation required for each shot once the lasers were installed on the concrete wall of the facility. At only 14 m from the driver wall the shock front was not yet a vertical plane. Therefore, the slope of the shockwave had to be estimated to compute shock overpressure. Even so, the overpressure values obtained compare reasonably well with those obtained from pressure rake measurements located a few feet downstream of the laser beams.

With a full (~16 beams) array of laser beams, the planarity of the shock front and the shock overpressure could be measured with high accuracy, with the flowfield free of instrumentation such as pressure gauges. Alternatively, a three-beam array positioned at the same station as key pressure rake measurements would provide a high-accuracy check of the latter.

The laser beam array proved highly reliable. A permanent such array would be low-maintenance and would require a minimum of preparation prior to each test shot.

PREFACE

The work reported here was performed under Contract DNA001-95-C-0086, a Phase II, Small Business Innovative Research (SBIR) effort. Mr. Mark Flohr, Lt. Col. T. Sidney Chivers, USA, and Lt. Col. James C. O'Shaughnessy, USA, were DSWA's technical monitors in succession. The authors express special thanks to Lt. Col. Frank W. Moynihan, LB/TS Director and Mr. Howard Ross, of DSWA Field Command, and to Mr. Derry Webb, AlliedSignal Inc., for their help and cooperation during the course of the project.

CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY ⟶ BY ⟶ TO GET
TO GET ⟵ BY ⟵ MULTIPLY

angstrom	1.000 000 X E -10	meters (m)
atmosphere (normal)	1.013 25 X E +2	kilo pascal (kPa)
bar	1.000 000 X E +2	kilo pascal (kPa)
barn	1.000 000 X E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 X E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm^2)	4.184 000 X E -2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 X E +1	* giga becquerel (GBq)
degree (angle)	1.745 329 X E -2	radian (rad)
degree Fahrenheit	$t_K = (t°f + 459.67)/1.8$	degree Kelvin (K)
electron volt	1.602 19 X E -19	joule (J)
erg	1.000 000 X E -7	joule (J)
erg/second	1.000 000 X E -7	watt (W)
foot	3.048 000 X E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 X E -3	meter^3 (m^3)
inch	2.540 000 X E -2	meter (m)
jerk	1.000 000 X E +9	joule (J)
joule/kilogram (J/kg) radiation dose absorbed	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 X E +3	newton (N)
kip/inch^2 (ksi)	6.894 757 X E +3	kilo pascal (kPa)
ktap	1.000 000 X E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 X E -6	meter (m)
mil	2.540 000 X E -5	meter (m)
mile (international)	1.609 344 X E +3	meter (m)
ounce	2.834 952 X E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 X E -1	newton-meter (N-m)
pound-force/inch	1.751 268 X E +2	newton/meter (N/m)
pound-force/foot^2	4.788 026 X E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 X E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214 011 X E -2	kilogram-meter^2 (kg-m^2)
pound-mass/foot^3	1.601 846 X E +1	kilogram/meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000 000 X E -2	** Gray (Gy)
roentgen	2.579 760 X E -4	coulomb/kilogram (C/kg)
shake	1.000 000 X E -8	second (s)
slug	1.459 390 X E +1	kilogram (kg)
torr (mm Hg, 0°C)	1.333 22 X E -1	kilo pascal (kPa)

* The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
** The Gray (Gy) is the SI unit of absorbed radiation.

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SECTION 1

INTRODUCTION

Two optical techniques were proven on the Defense Nuclear Agency (DNA) Middle Key 4 HE Shot for measuring air shock front arrival at selected distances from the charge (Carpenter and Michalski, 1993)*. Close to the surface of the charge (1000's of psi) where the shock front glowed because of the high-temperature shocked air, a shocklight technique was used. This technique focuses a camera lens on a narrow "slit" in space; when the glowing shockfront arrives at that virtual slit, the narrow bright image is optically focused by a lens system onto the end of a fiber optic cable. The light is transmitted through the fiber to a detector which transforms the optical signal into an electrical signal for recording.

When the shockwave strength is too weak to make the air glow (few 1000's of psi and below), a separate light source is needed. At selected ranges from the MK-4 charge a small laser beam was focused across the shockwave path, into an optical fiber. From that point the circuit is the same as for the shocklight technique, except that when the shockwave "breaks" the laser beam the light signal goes off--just the opposite of the shocklight technique.

Carpenter Research Corporation (CRC) proposed to instrument the Defense Special Weapons Agency's (DSWA) Large Blast and Thermal Simulation (LB/TS) with an array of 16 laser beams which would characterize the blast front produced by the LB/TS at the test section of the simulator. The 16-beam orthogonal array was designed to measure the planarity of the shock front approaching the test section as well as the shock overpressure. However, before the optical array could be installed DSWA decided to leave physical pressure probes in the shockpath as "permanently" installed diagnostics, and considered the optical array unnecessary.

Subsequently, DSWA personnel decided to employ nine of the optical instruments to measure the shock arrival just downstream of the LB/TS airblast driver tubes for diagnosing the temporal performance of the latter. Before such an array of the instruments was installed, a second DSWA decision was made to, instead, place a few channels of laser beams at a station 14 meters downstream of the airblast driver-tube exits to check out the

* Carpenter, H. J., and Michalski, D. J., "Middle Key 4 Optical TOA Measurements," CRC-9110-FR, December 1993 (Phase I SBIR Study conducted for the Defense Nuclear Agency).

optical instruments and to assist in characterizing the blast at that station produced by LB/TS test shots using only one or two drivers.

This report describes the optical instrumentation and presents the results from three LB/TS test shots employing a single driver tube.

SECTION 2

DESCRIPTION OF OPTICAL INSTRUMENTATION

2.1 SYSTEM SCHEMATIC.

Figure 2-1 outlines a laser Time of Arrival (TOA) channel used during the LB/TS test shots reported herein. A more permanent installation might use an electronic DC power supply; however, for these limited tests a 6-volt Lithium battery with an off-on toggle switch supplied power for each laser. The small, mm size laser beam was directed across the LB/TS tunnel into a set of collecting optics (a large circular lens and a GRIN lens) which focused the laser beam into the receiving end of a single-strand optical cable. The beam traveled through the cable, which exited the tunnel and ran to the data recording room.

Figure 2-2 shows the optical fiber cable entering a photodetector/amplifier box, where the beam is directed into a silicon photodetector. The latter is powered by a 9-volt battery. The magnitude of the electrical signal coming from the photodetector is proportional to the *received* laser beam strength. A solid-state amplifier powered by two 6-volt Lithium batteries conditioned the electrical signal for transmission through a standard RG 50 electrical cable to the DSWA digital recorder.

When the shock front traveling down the LB/TS tunnel intersects the laser beam, the beam is diffracted by the air density discontinuity across the shock, such that it no longer is collected by the collecting optics lens. The time required for the shockwave to travel across the laser beam is equal to the time of the signal in the data recorder to go from the full-strength to the zero-strength levels. The shock TOA at the laser beam is taken as the time at one-half the signal excursion from its pre-TOA level to its "zero" level--that is, the time at which the shock wave has traveled halfway across the laser beam.

2.2 LASER LIGHTBEAM SOURCE.

The Power Technology, Inc., Standard OEM Diode Laser PM03 (670-5) was used to produce a one-milliwatt laser beam. The wavelength of the red light produced is 670 nm. The beam is collimated so that its width did not exceed 5 mm in the horizontal plane anywhere along its path across the LB/TS tunnel.

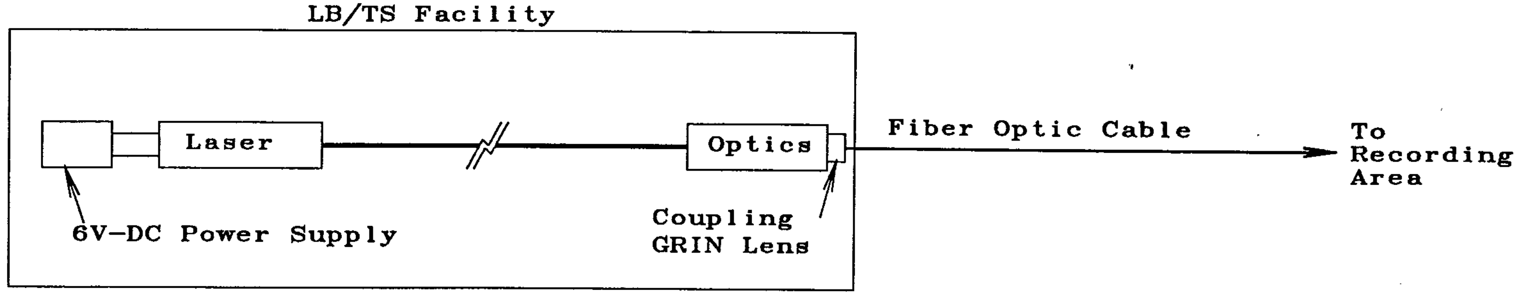


Figure 2-1. Schematic of LB/TS optical TOA system.

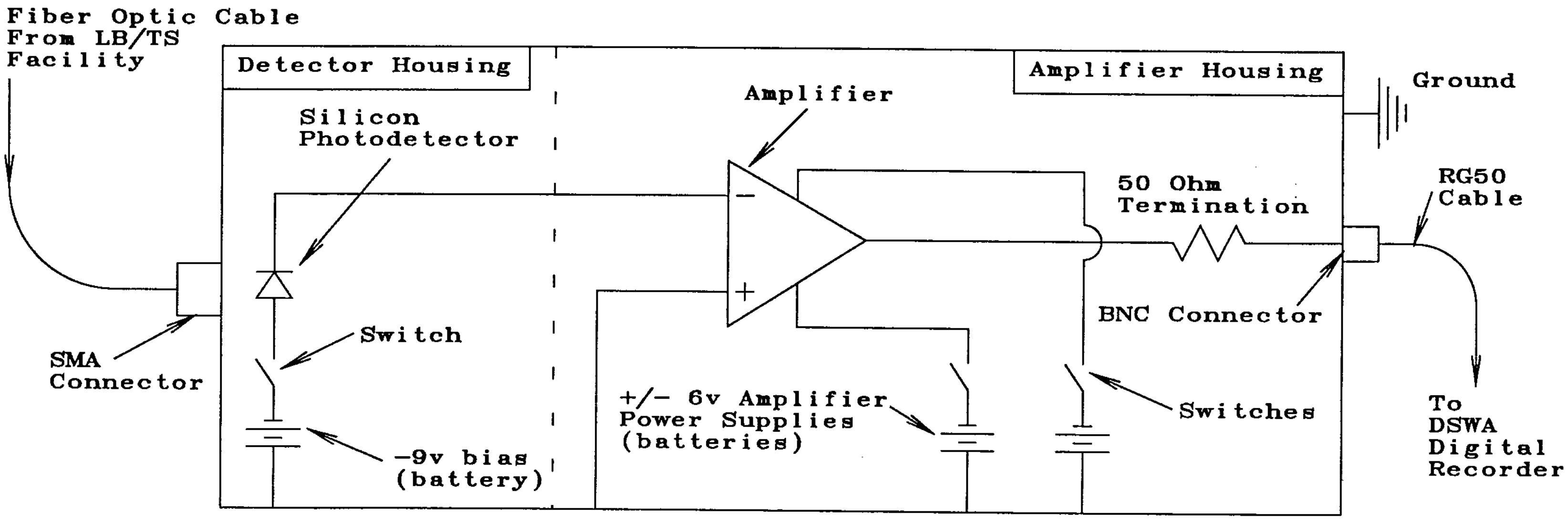


Figure 2-2. Schematic of CRC photodetector/amplifier circuit.

As shown in Figure 2-3 (approximately full scale), the laser was housed in a strong aluminum box on an adjustable mount. This box was bolted to an "angle block" for mounting to the LB/TS wall. Threaded anchor caps were secured in the concrete LB/TS wall with Epoxy, and the laser box/angle block was bolted onto the wall via these caps. The front plate of the housing box was fitted with a glass window to accommodate the laser beam. It also contained two normally plugged holes through which the laser beam path was adjusted so that it was centered on the collecting lens across the tunnel. Power supply lines are shown in Figure 2-3 which would supply power to the laser from a remote location. However, for the limited, 4-beam installation reported on herein, a small 6-volt Lithium battery was mounted in the housing box and used for power.

2.3 OPTICAL RECEIVERS.

The laser beam was focused on the center of a 2-in diameter lens housed in an aluminum box similar to that used for the laser. As shown in Figure 2-4, this lens and a GRIN (gradient index) lens were also adjustable as a unit.

2.4 OPTICAL TRANSMISSION CABLES.

The fiber optic cable used for laser beam transmission was the 3M TECS 39, High - OH^-, 200-µm, silica-core type, whose numerical aperture is 0.39. Kevlar strands and a 3-mm diameter PVC jacket covers the glass fiber core. The attenuation of the 670 nm light along the fiber is 4 dB/km. At 820 nm wavelength, the band width of the fiber is 20 MHz/km. SMA 905 connectors were used to terminate each end of the fiber. Each cable was about 700 ft long.

2.5 OPTICAL DETECTORS/AMPLIFIERS.

Silicon Detector Corporation Model 100-12-22-021 high frequency silicon photodetectors with blue enhanced spectral response were used to detect the laser light at the end of the fiber optic cables. These detectors transformed the light signal into an electrical signal which was amplified by Comlinear Corporation Model CLC-420 operational amplifiers to drive the transmission line to the DSWA digital recorder at volt levels.

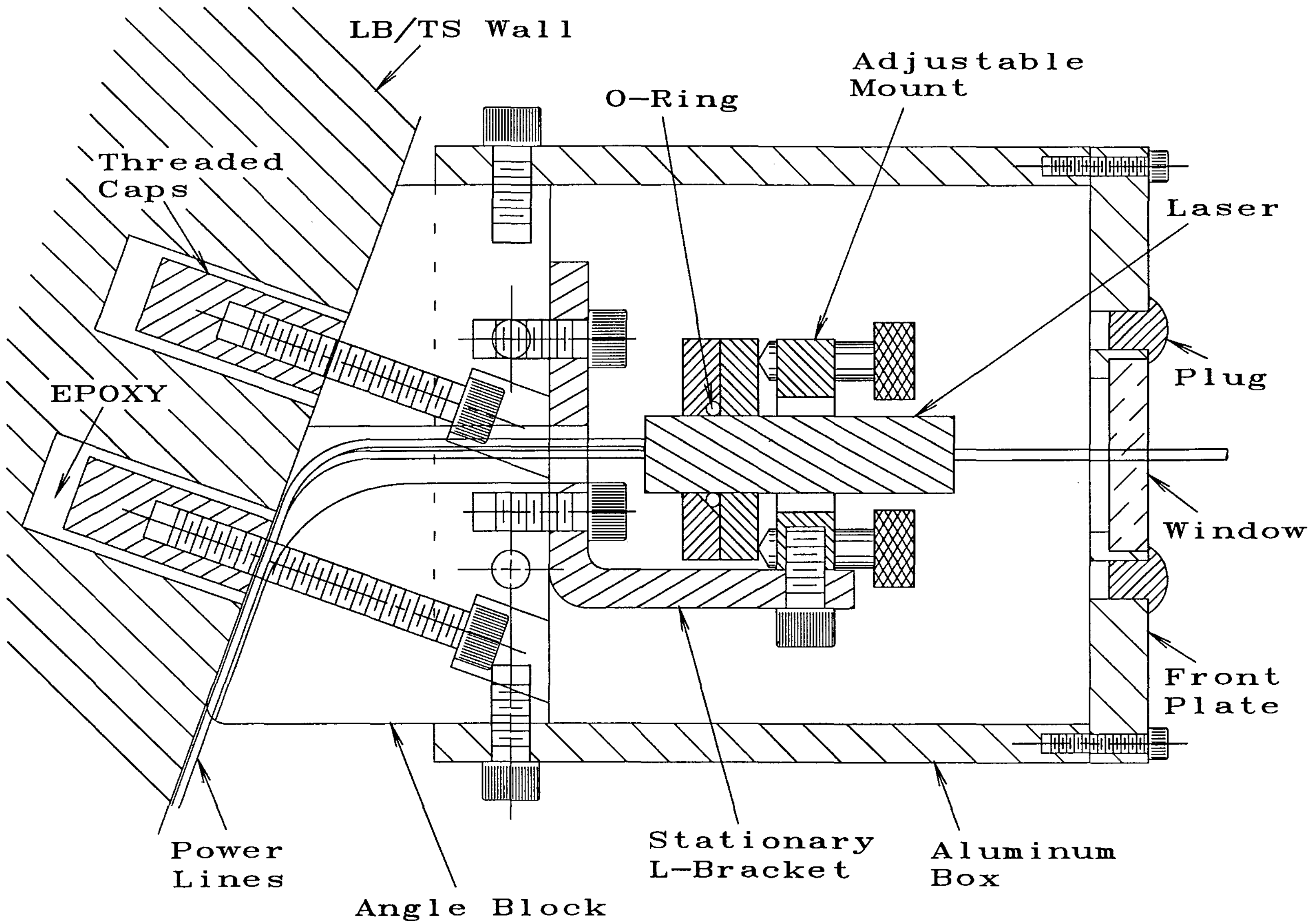


Figure 2-3. Assembly drawing of laser mounting/adjusting apparatus.

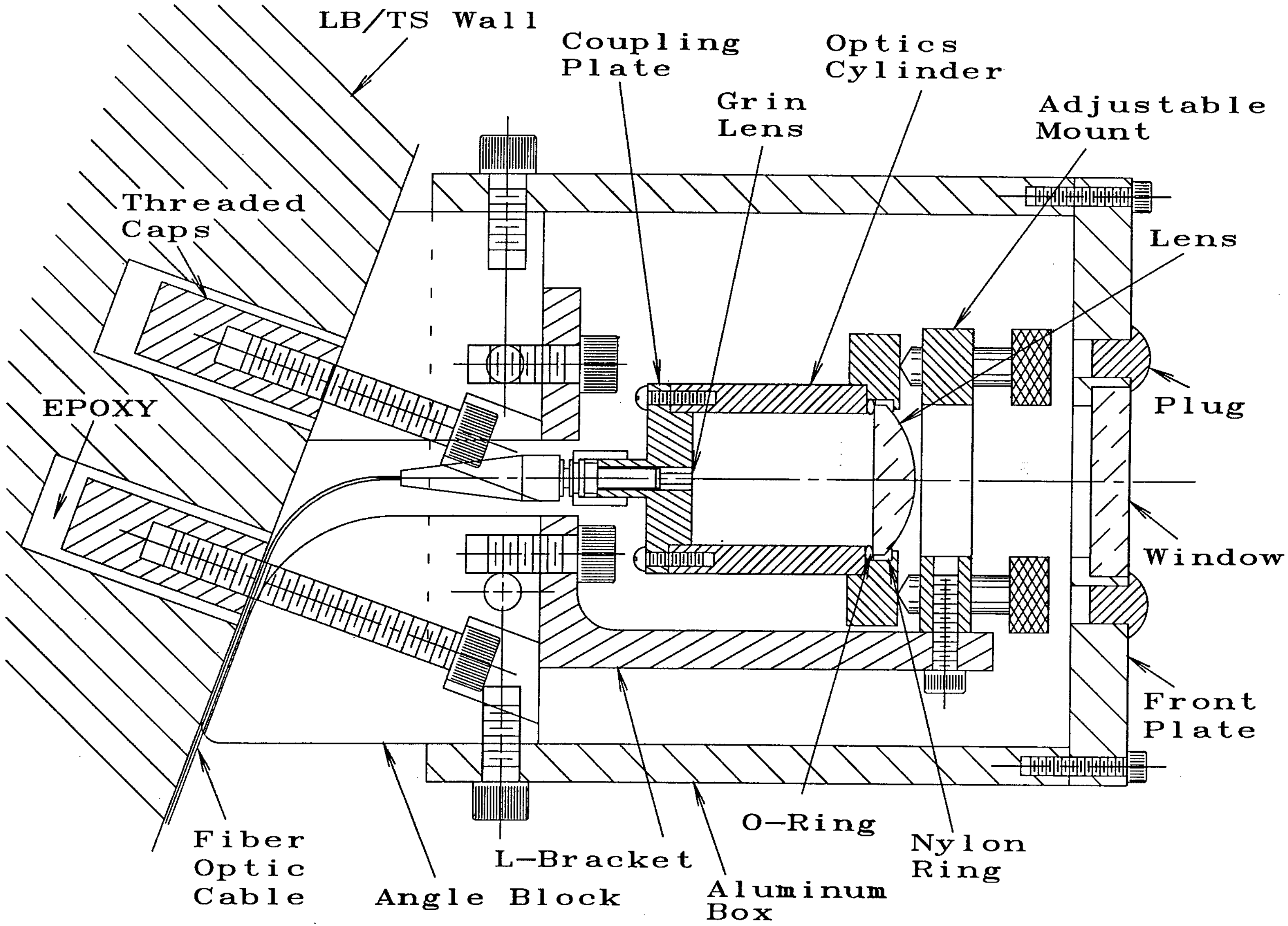


Figure 2-4. Assembly drawing of optics mounting/adjusting apparatus.

2.6 DSWA SIGNAL RECORDERS.

Each laser channel signal was recorded on one of DSWA's Pacific Instruments Model 9820 digital recorders. These records were set at a signal sampling rate of 500 k samples/sec. They have a storage capacity of 128 kbytes. The recorder amplitude was set at ± 1 volt. The accuracy of the recorders in elapsed time is 2 μsec at the recording speed used . An appropriate fiducial signal from the blast driver tube firing circuit was used to trigger the recording system.

The data were downloaded from the recorder to a computer where they were saved on a hard drive and copied onto floppy disks for CRC's use.

SECTION 3

LASER BEAM CONFIGURATIONS FOR LB/TS

Three (3) laser beam arrays were considered for use in LB/TS, with only one of them being used for this effort.

3.1 TEST SECTION LASER BEAM ARRAY.

As originally proposed by CRC, the 16-beam array shown by Figure 3-1 would be placed just upstream of the LB/TS test section to measure the planarity and shock overpressure of the blast wave as it approaches the test target. Any tilting or bending of the incident shockwave would be accurately detected and the overpressure accurately determined without the necessity of placing physical instrumentation in the flow close to the target. DSWA's decision to leave pressure rakes in the flow resulted in a following decision not to use the laser beam screen at that location.

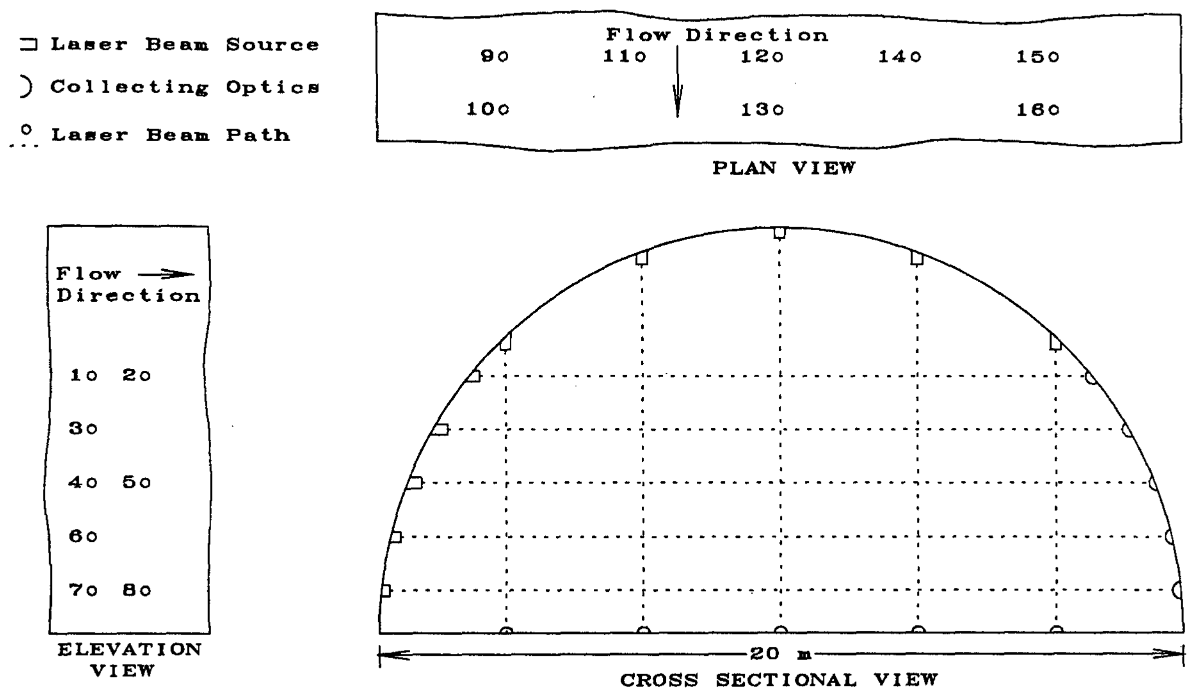


Figure 3-1. Proposed LB/TS test section laser beam array.

3.2 LB/TS DRIVER EXIT LASER BEAM ARRAY.

A second array considered was to place a second laser beam just downstream of the exit of each blast driver tube. The beam would be interrupted by the blast front as it emerges from the driver. This would establish the simultaneity of driver performance for a test in which multiple drivers are fired. Figure 3-2 is a schematic of the array. Since the driver tube array would utilize only nine of the 16 laser channels, the addition of one more channel (total of 17) would provide two sets of two beams at an intermediate tunnel station and two sets of two beams spanning the test section area. With this arrangement, one would obtain four shock overpressure values in addition to driver simultaneity information.

3.3 ARRAY USED AT THE 14-METER STATION.

The laser array actually installed and tested in LB/TS during this effort is sketched in Figure 3-3. The average range (half way between two tandem beams) of this station is from 34-in 42.375-in upstream of the pressure orifices located on the DSWA pressure probe rakes. The actual distance for each set of beams depends upon the test shot. Although only two vertical positions are provided for TOA measurements, some indication of the shock front skewness is provided. One would not expect the shock front to have developed into a vertical plane at a station so close to the drivers.

As indicated earlier, 6-volt batteries were used to power the lasers for this quite limited array. For a more permanent installation one might wish to provide a DC power supply from a remote location so that the lasers could be turned on and off from the facility's control room.

The boxes housing the laser and receiver optics were installed on the LB/TS wall with Loctite Dura Metal Epoxy securing the mount anchors in 9/16-in dia. by 1.5-in deep holes drilled into the concrete.

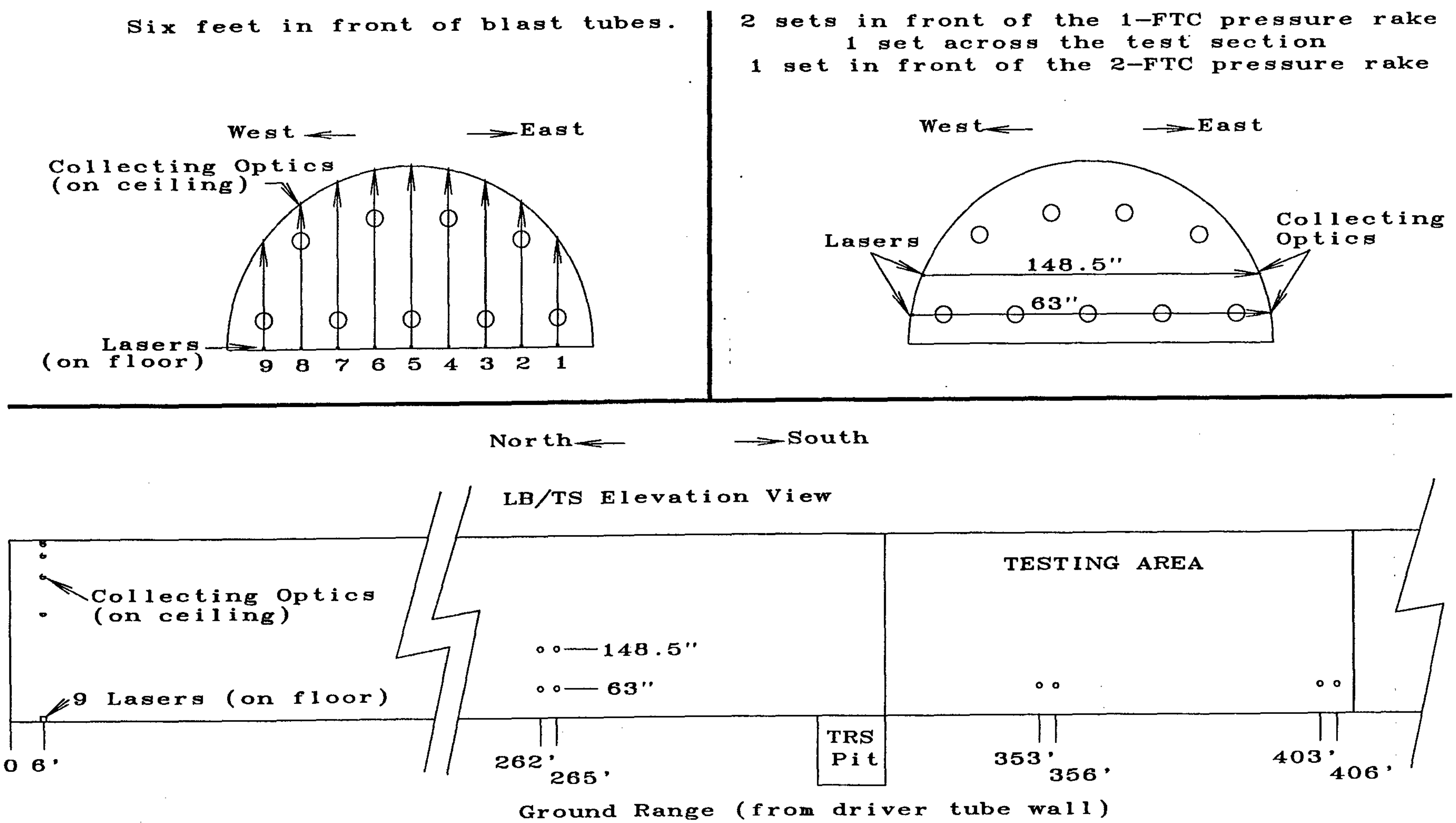
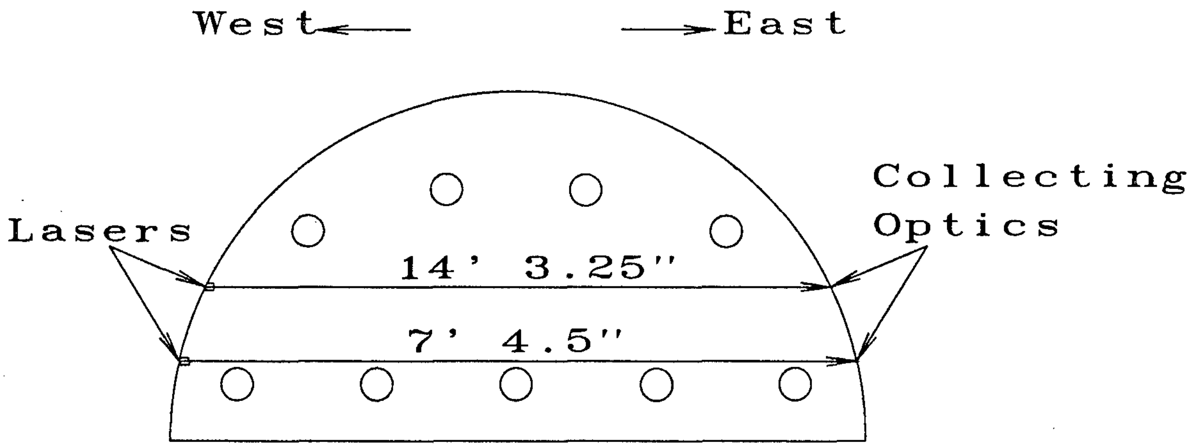


Figure 3-2. LB/TS driver exit laser beam array.



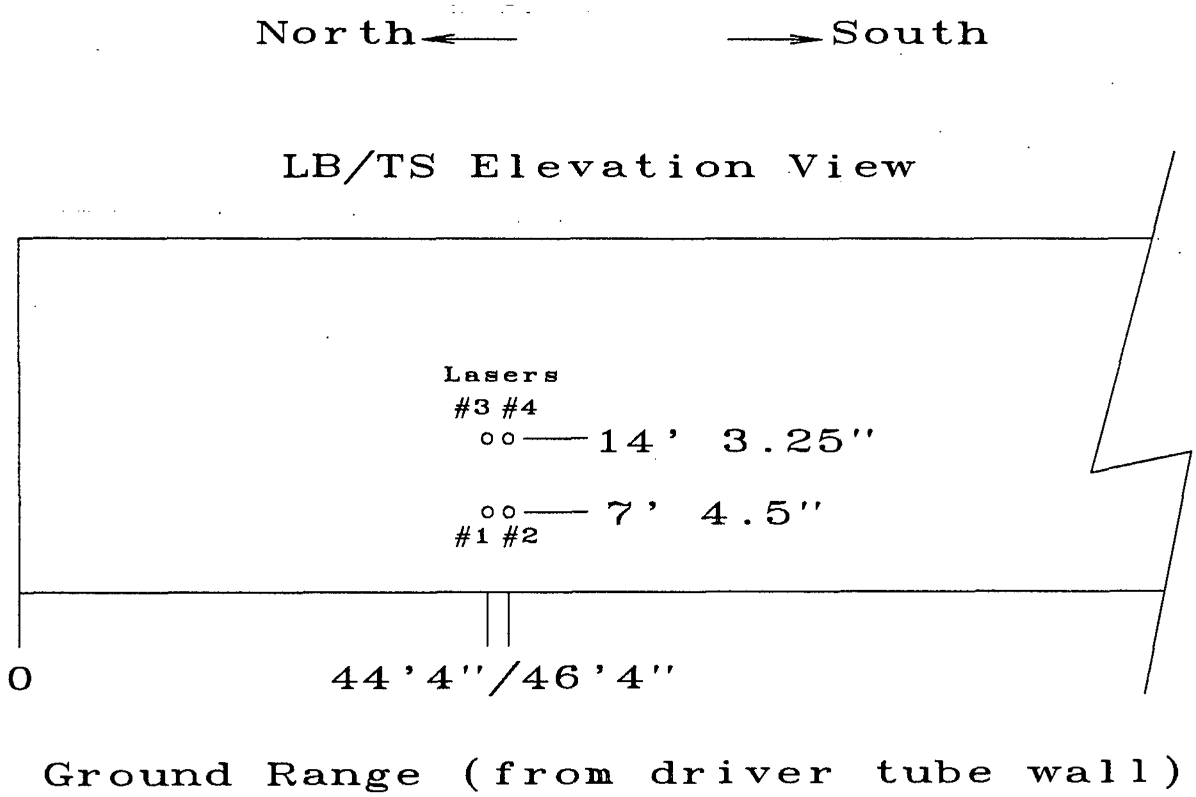


Figure 3-3. LB/TS laser beam array as installed, ~14 meters from driver tube wall.

SECTION 4

TEST RESULTS

4.1 TIME OF ARRIVAL (TOA) MEASUREMENTS AND RECORDING.

The basic laser beam recordings provided by DSWA are shown in Figures 4-1 through 4-12 for LB/TS Shots 1, 2, and 3, in this series of tests. Each of these shots used only a single driver (Driver #5). Notice the low positive amplitude signal just after time zero on all channels; this is interpreted as the laser collecting optics sensing light from the detonating explosive used to rupture the driver tube diaphragm. Observe the large vertically upward swing of the record indicating shock arrival followed by a reduced oscillatory signal for about 20 msec. During this period the laser beams were again penetrating the "shocked" air and falling on the collector optics. Then, the laser light "went off" again for all six of the beams at the 7-ft, 4.5-in elevation, and stayed off for some time. However, for Shots 1 and 2 (the two lower pressure shots) the beams at the 14-ft, 3.25-in elevation did not go back off after shock arrival, but the comparable beams for Shot 3 (the higher pressure shot) did. This subsequent beam interruption might have been caused by dust arriving at the station. During the two lower pressure shots less dust might have entered the beam paths at the higher elevation than for the higher pressure shot.

The first several milliseconds of the records is shown in Figures 4-13 through 4-15. The digital data points are indicated by the small circles on each record. The center of the signal rise is taken as the shock TOA, indicated by the intersection of the point-to-point plotted curve and the horizontal dashed line. The vertical short-dash lines indicate the uncertainty of the TOA measurement, which is typically ± 0.5 μsec.

Table 4-1 summarizes the TOA values measured for each of the three shots.

4.2 SHOCK FRONT INCLINATION.

Inspection of the TOA values given in Table 4-1 reveals, as expected, that the shock front was not a vertical plane at the laser measurements station. The shock arrived from 1.0398 to 1.0611 ms later at the upper station than at the lower for Shots 1 and 2, and from 1.0808 to 1.0940 ms later for Shot 3. This suggests a mean shock "tilt" upstream of about 1.4 ft at the upper beams relative to the lower for Shot 3, and about 1.25 ft for Shots 1 and 2.

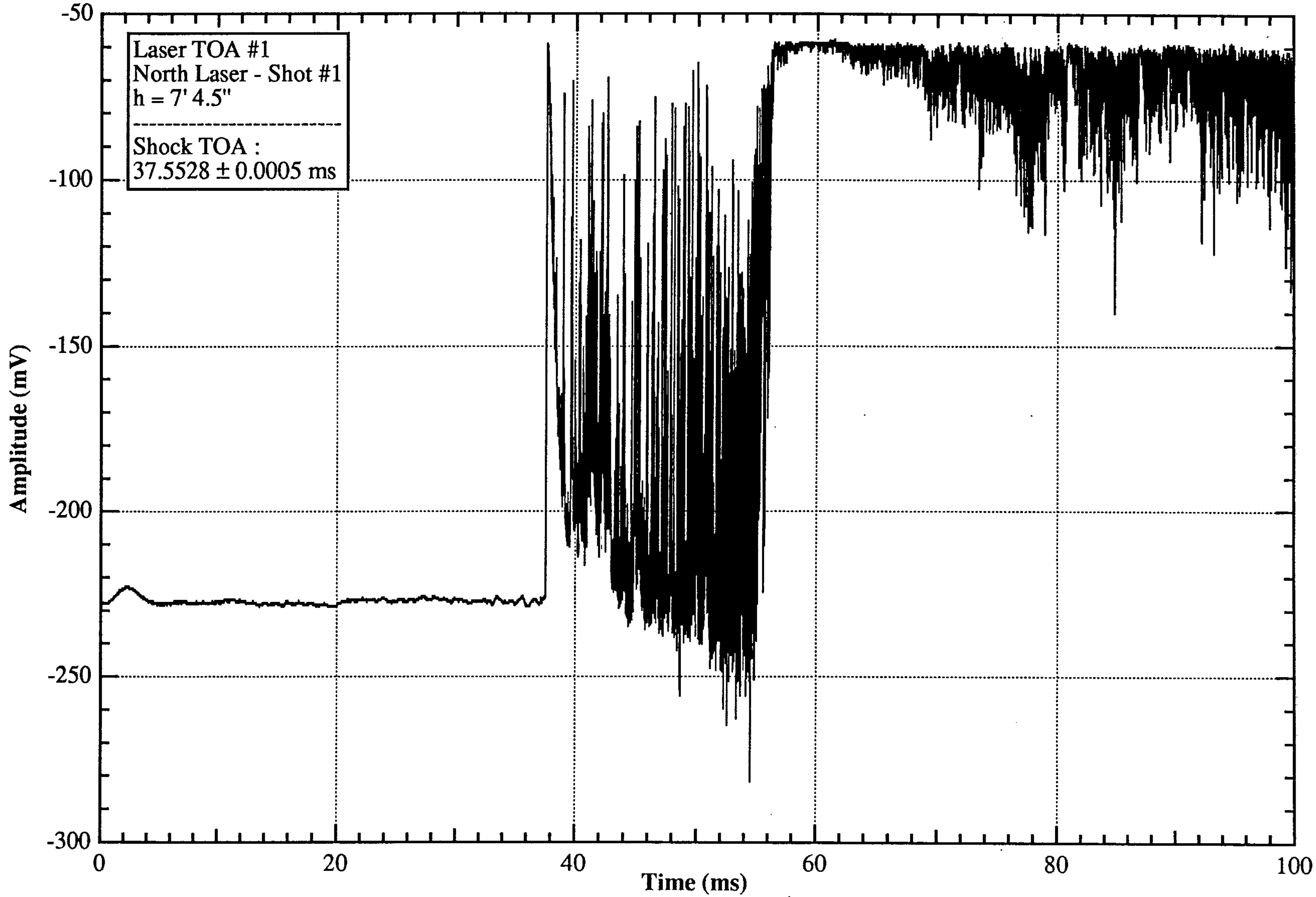


Figure 4-1. CRC laser TOA#1 data for LB/TS single driver Shot#1 (3/19/97).

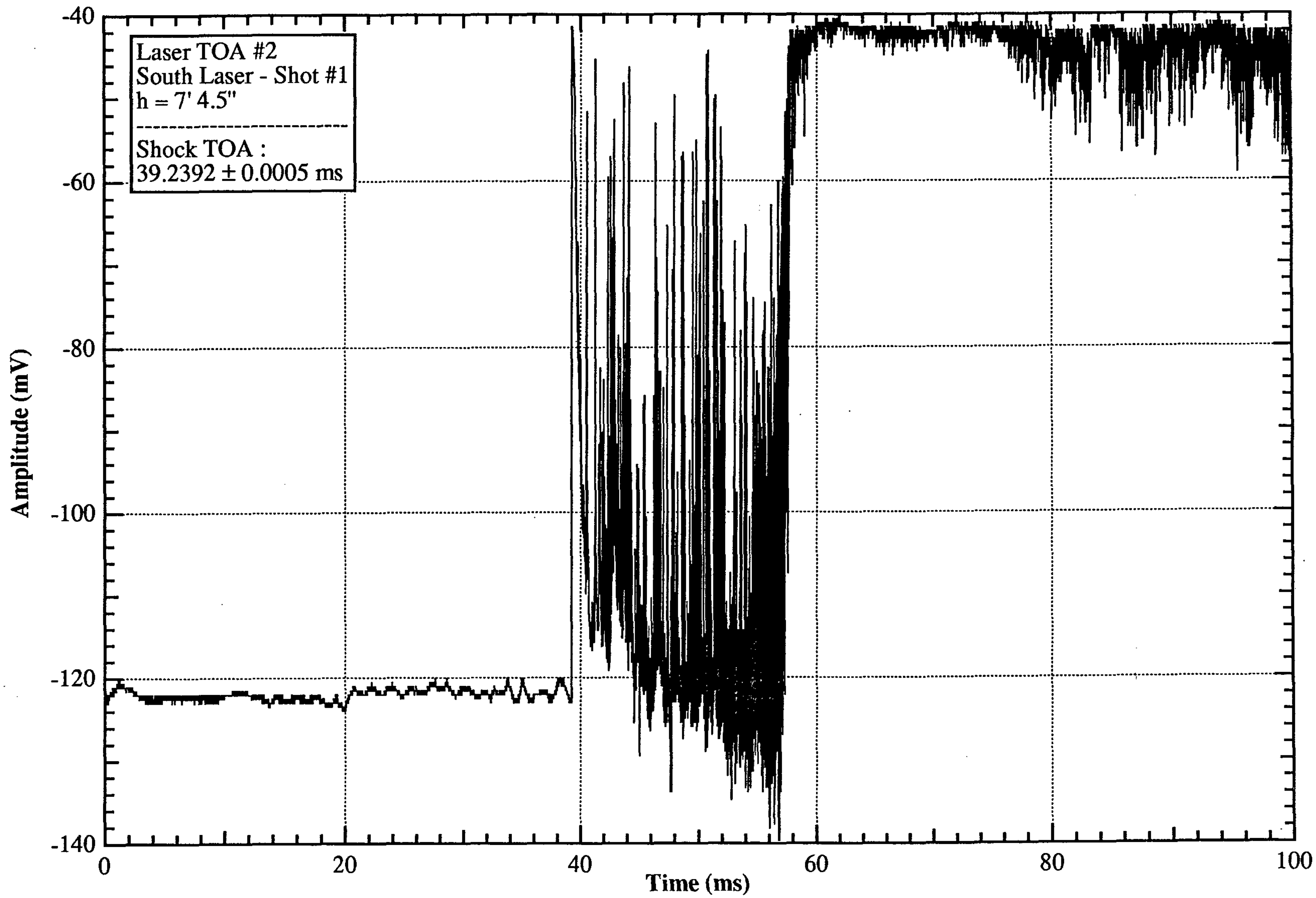


Figure 4-2. CRC laser TOA#2 data for LB/TS single driver Shot#1 (3/19/97).

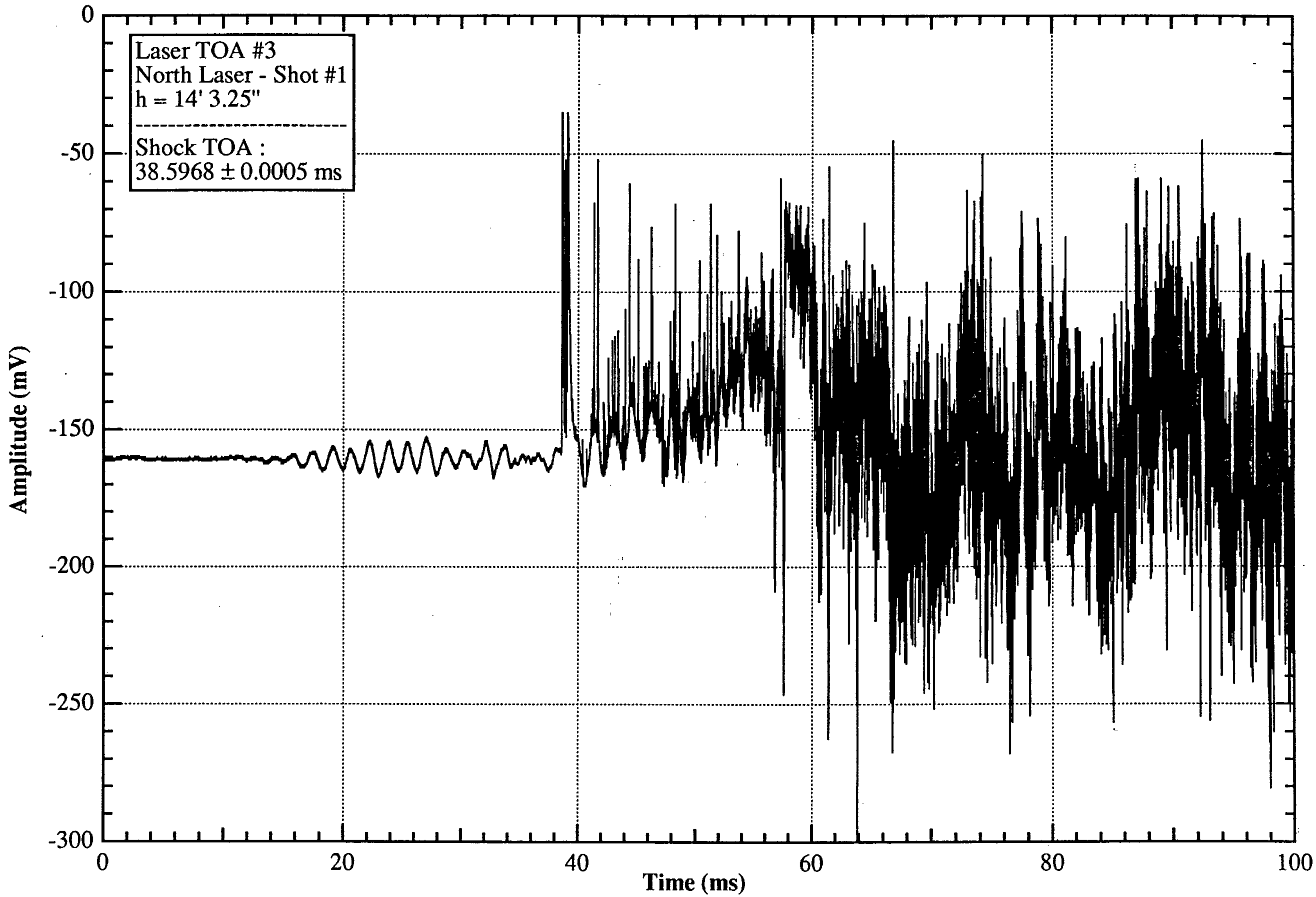


Figure 4-3. CRC laser TOA#3 data for LB/TS single driver Shot#1 (3/19/97).

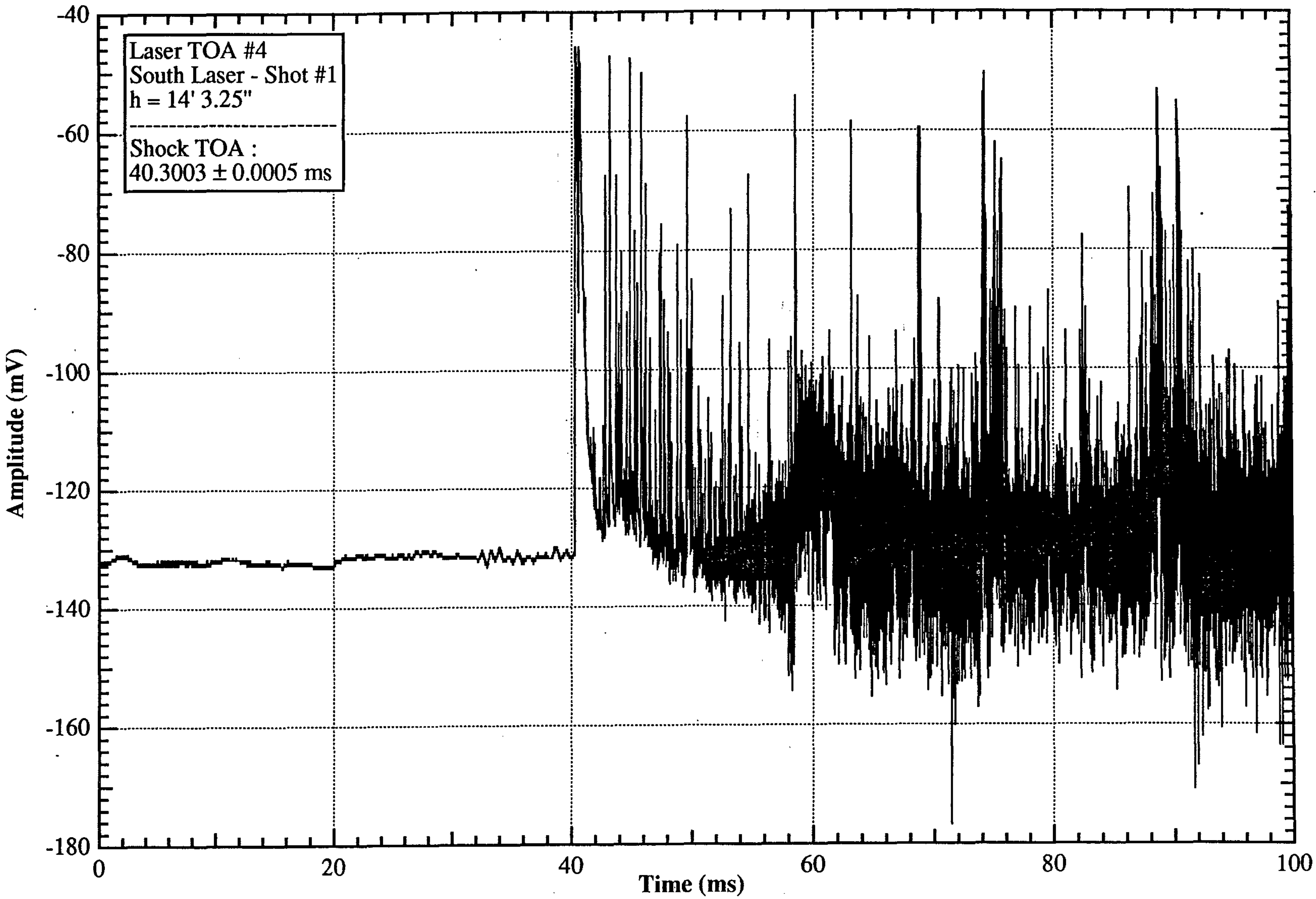


Figure 4-4. CRC laser TOA#4 data for LB/TS single driver Shot#1 (3/19/97).

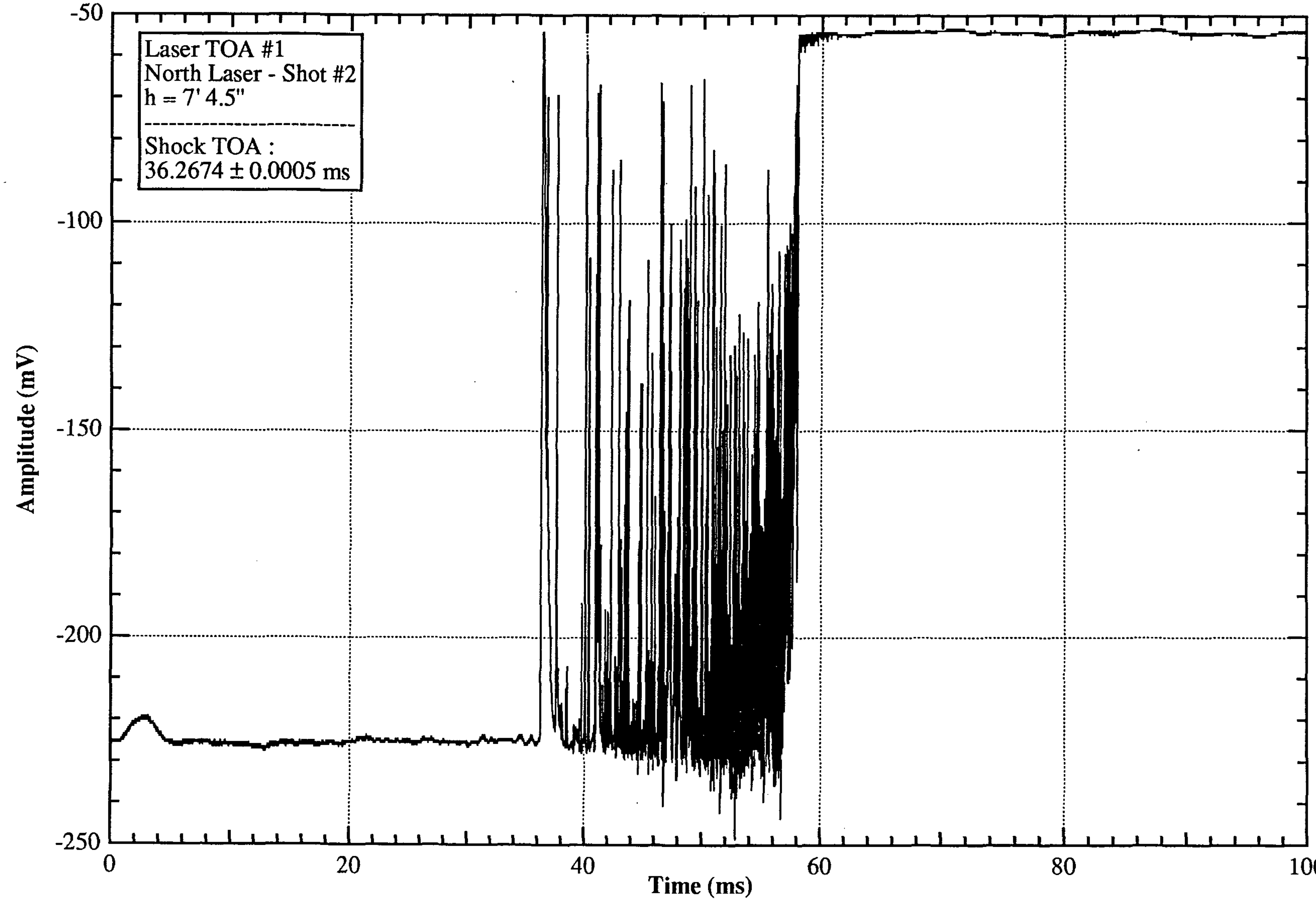


Figure 4-5. CRC laser TOA#1 data for LB/TS single driver Shot#2 (5/15/97).

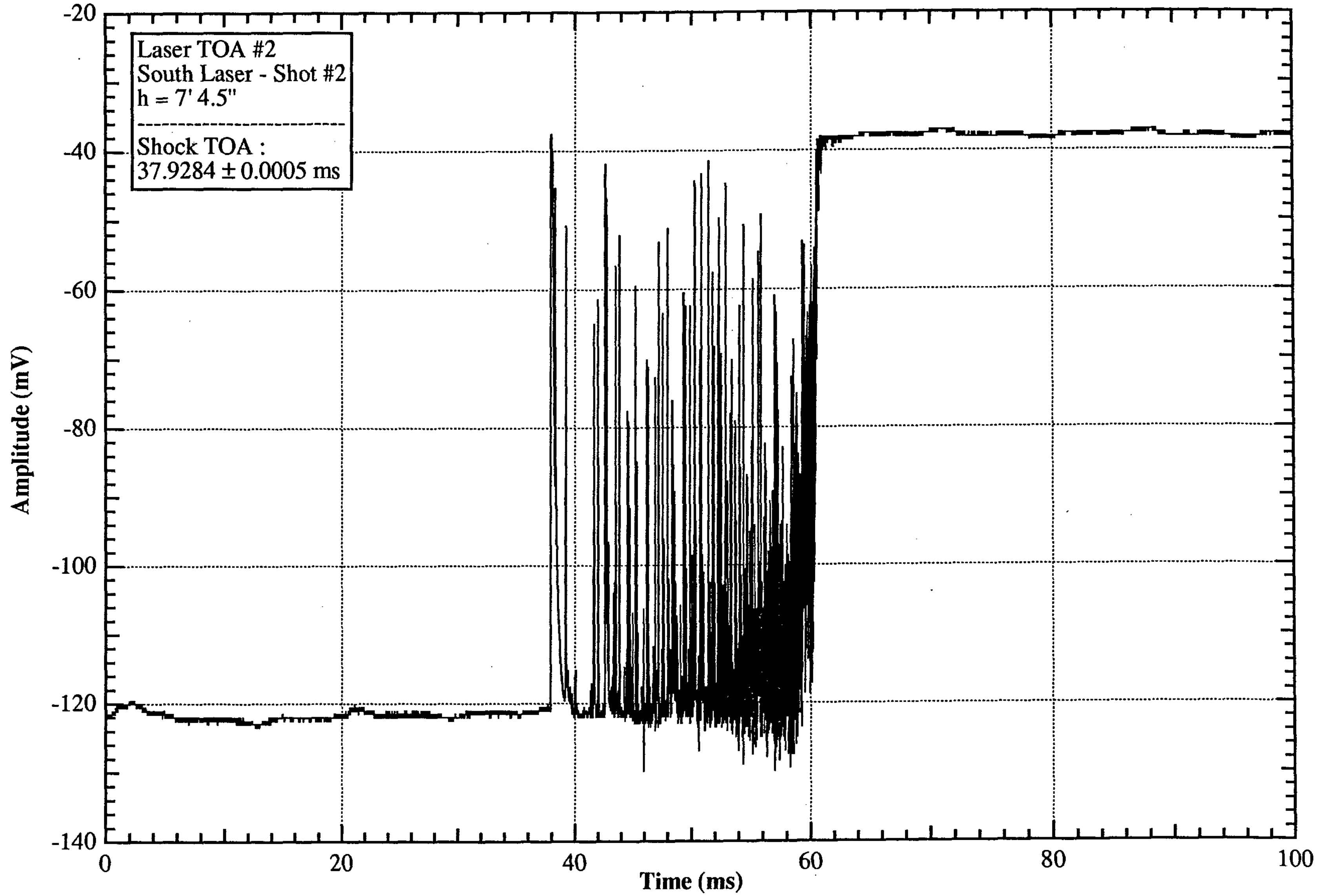


Figure 4-6. CRC laser TOA#2 data for LB/TS single driver Shot#2 (5/15/97).

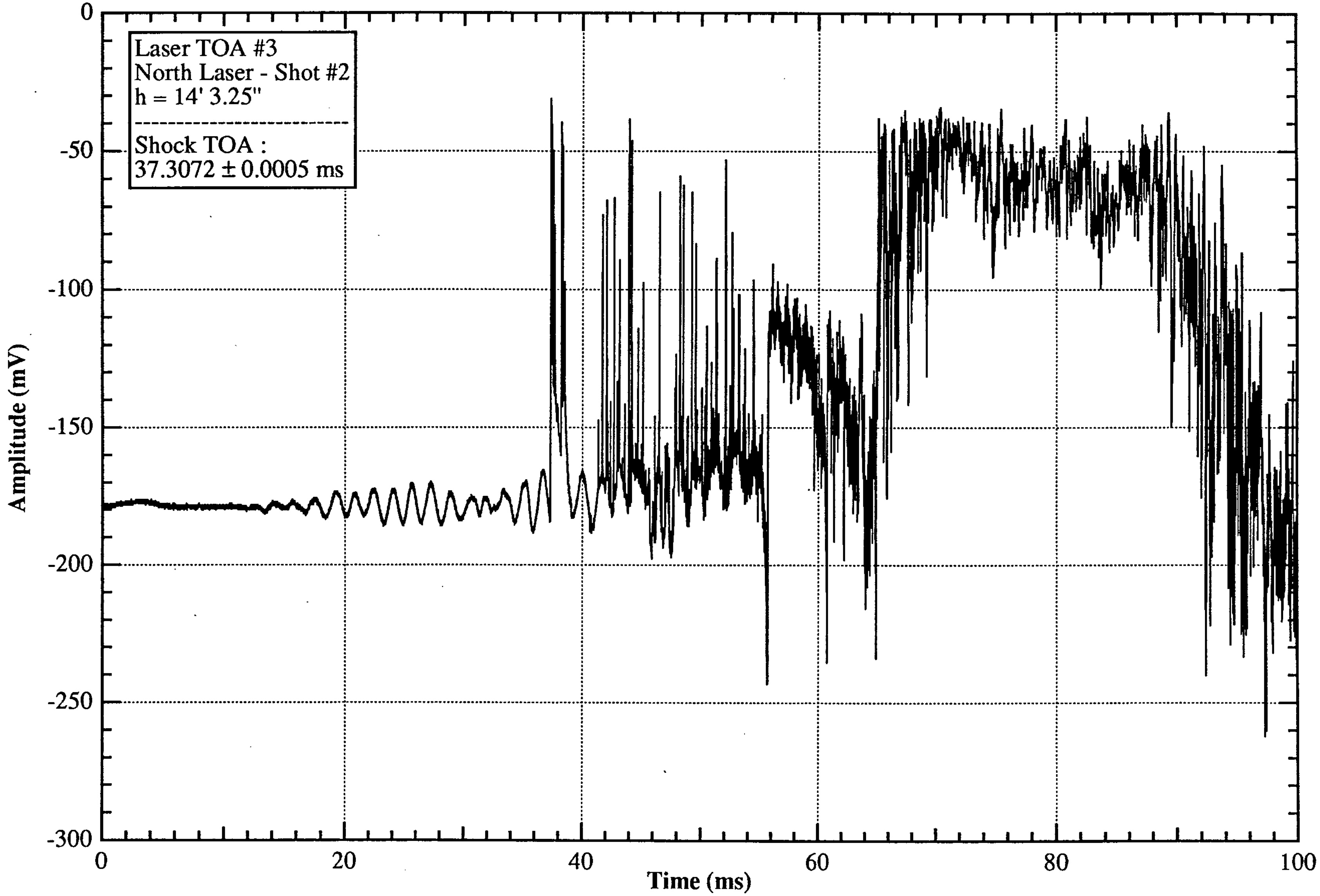


Figure 4-7. CRC laser TOA#3 data for LB/TS single driver Shot#2 (5/15/97).

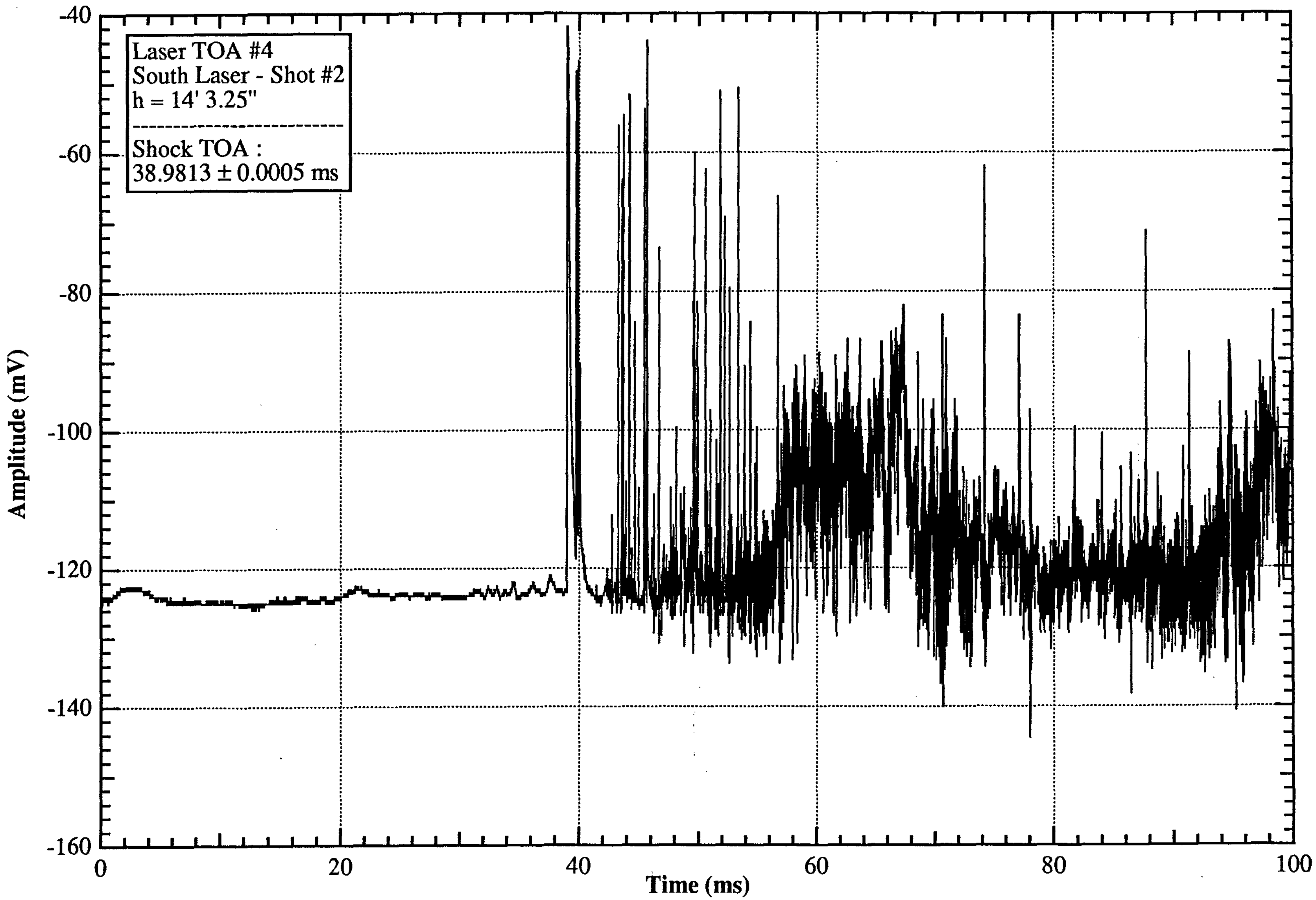


Figure 4-8. CRC laser TOA#4 data for LB/TS single driver Shot#2 (5/15/97).

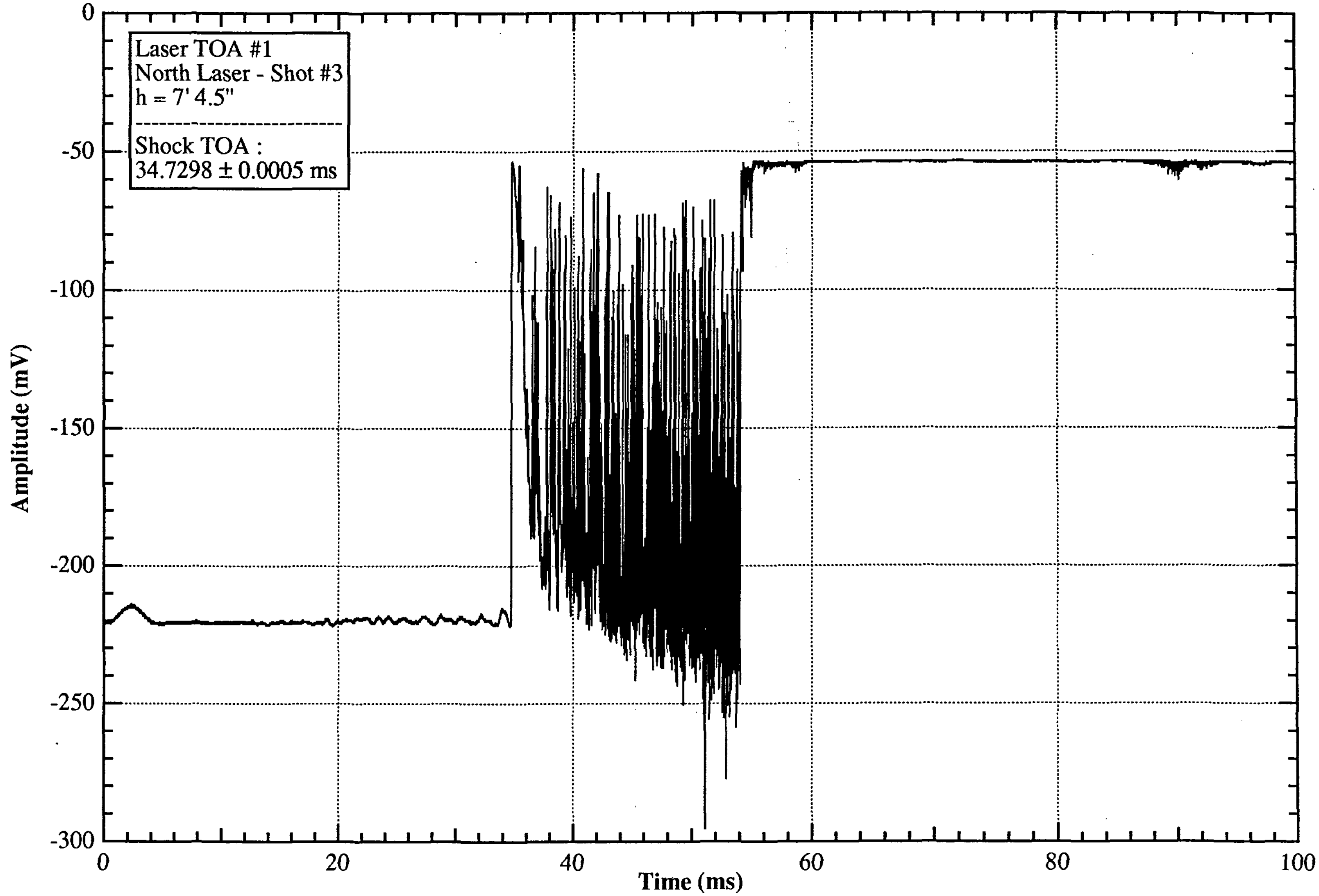


Figure 4-9. CRC laser TOA#1 data for LB/TS single driver Shot#3 (6/25/97).

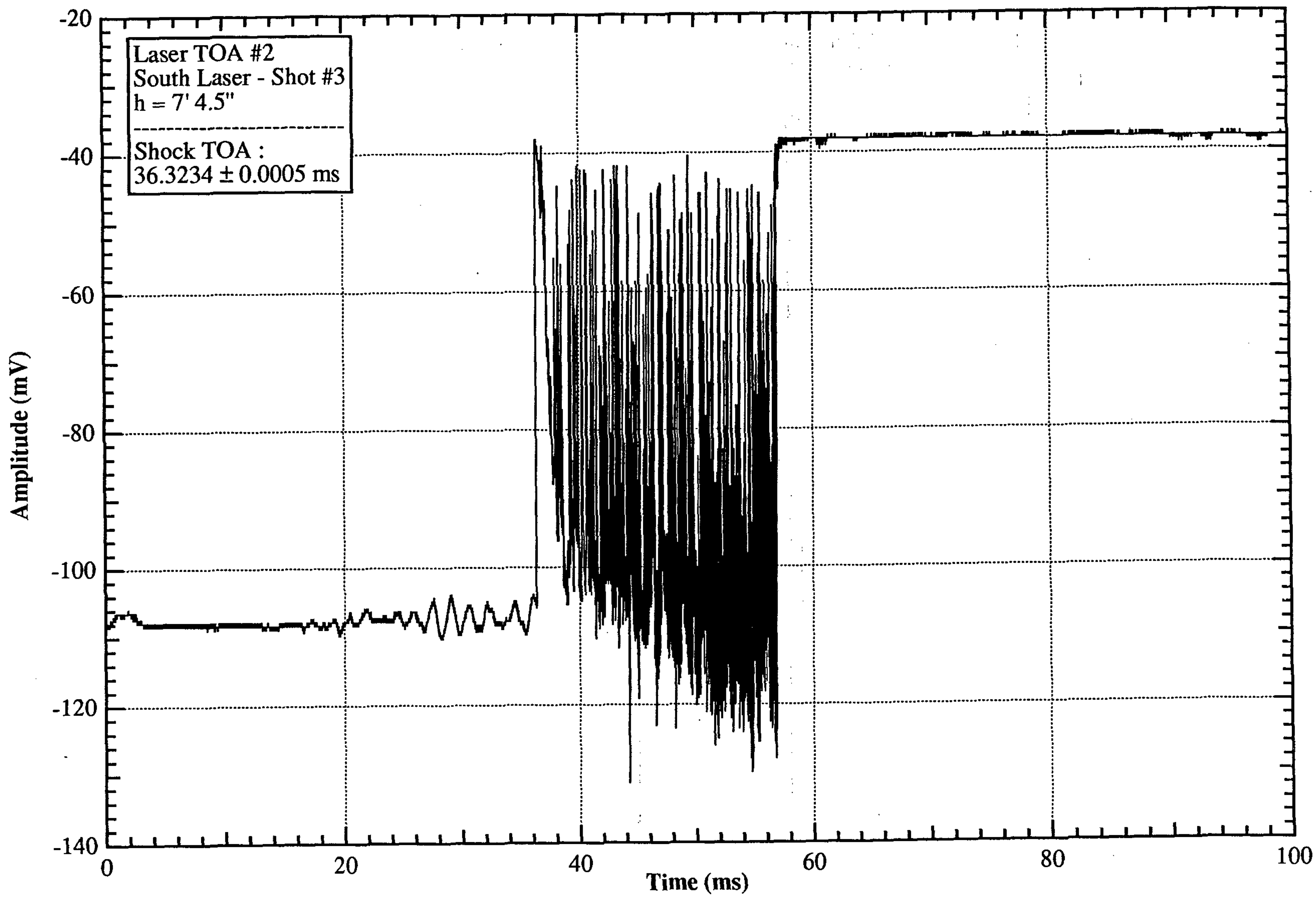


Figure 4-10. CRC laser TOA#2 data for LB/TS single driver Shot#3 (6/25/97).

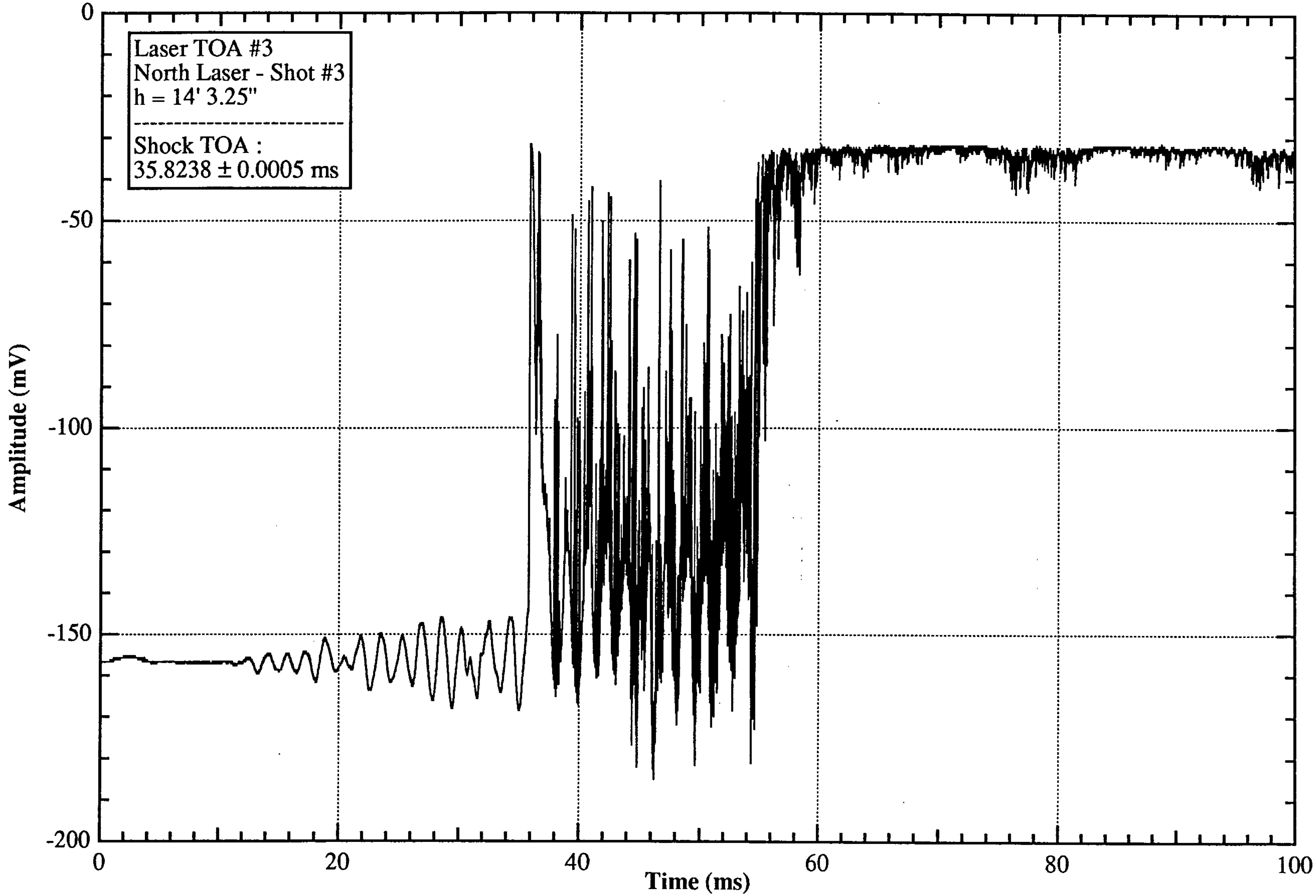


Figure 4-11. CRC laser TOA#3 data for LB/TS single driver Shot#3 (6/25/97).

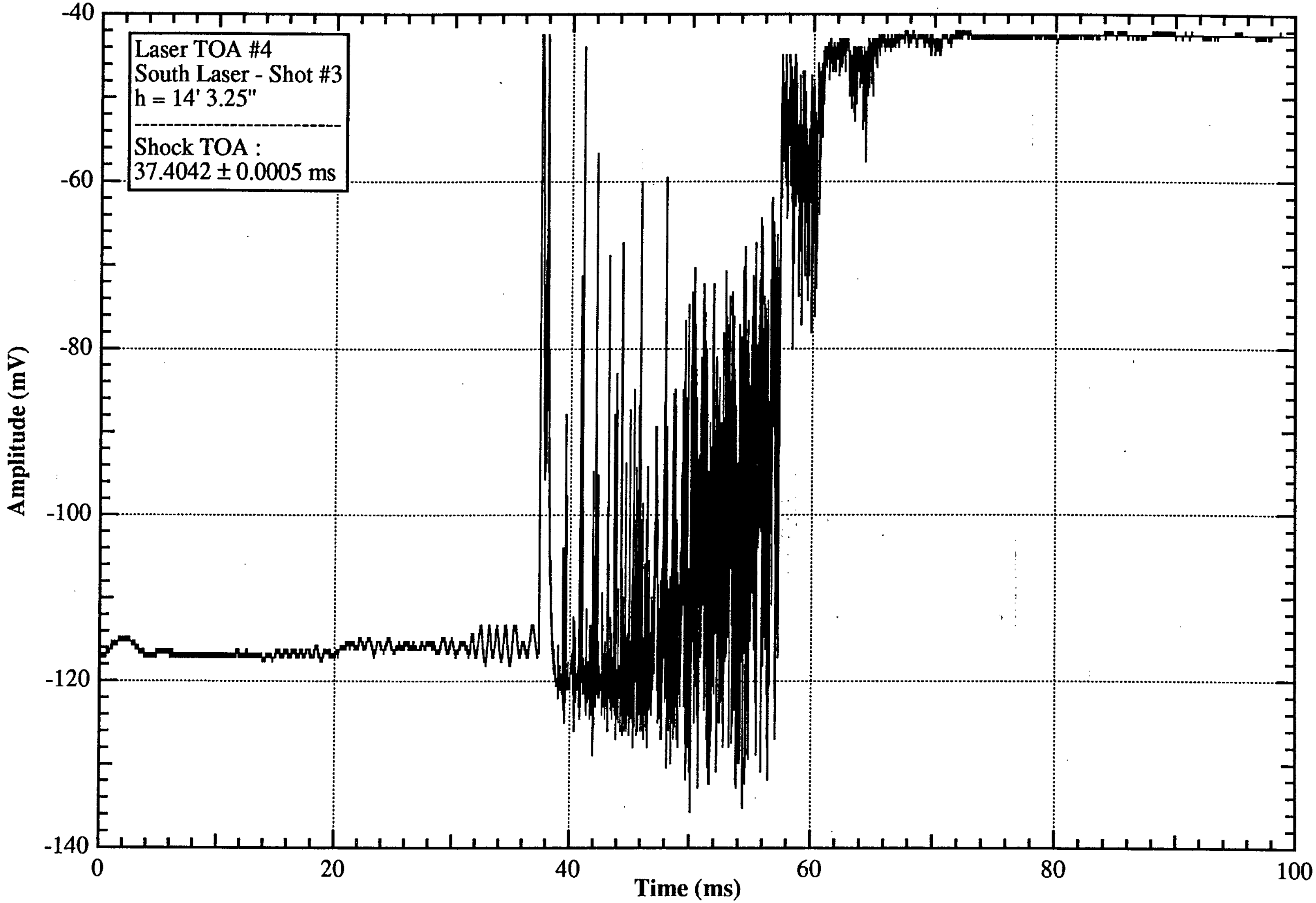


Figure 4-12. CRC laser TOA#4 data for LB/TS single driver Shot#3 (6/25/97).

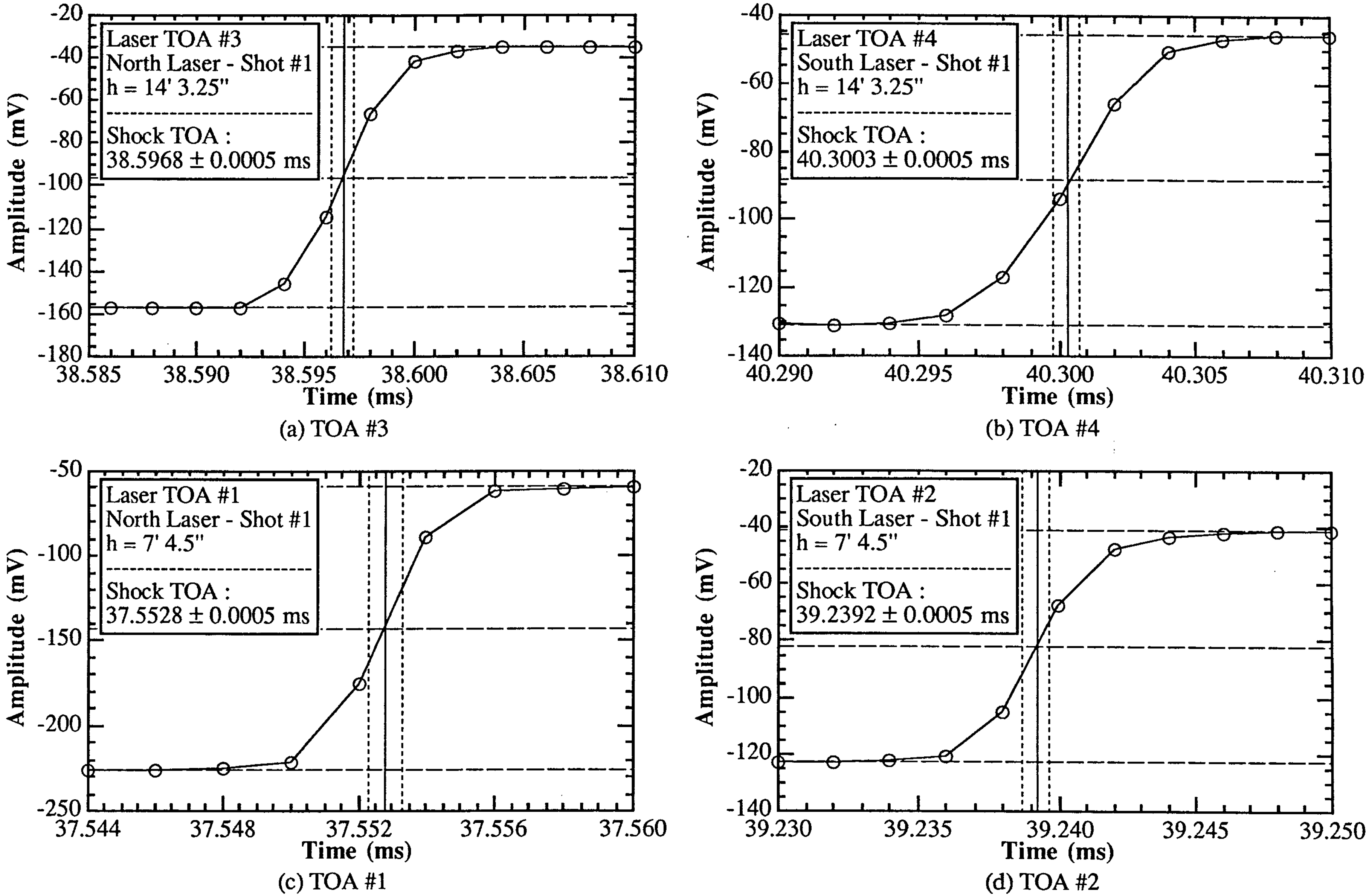


Figure 4-13. CRC laser TOA determination for LB/TS single driver Shot #1 (3/19/97).

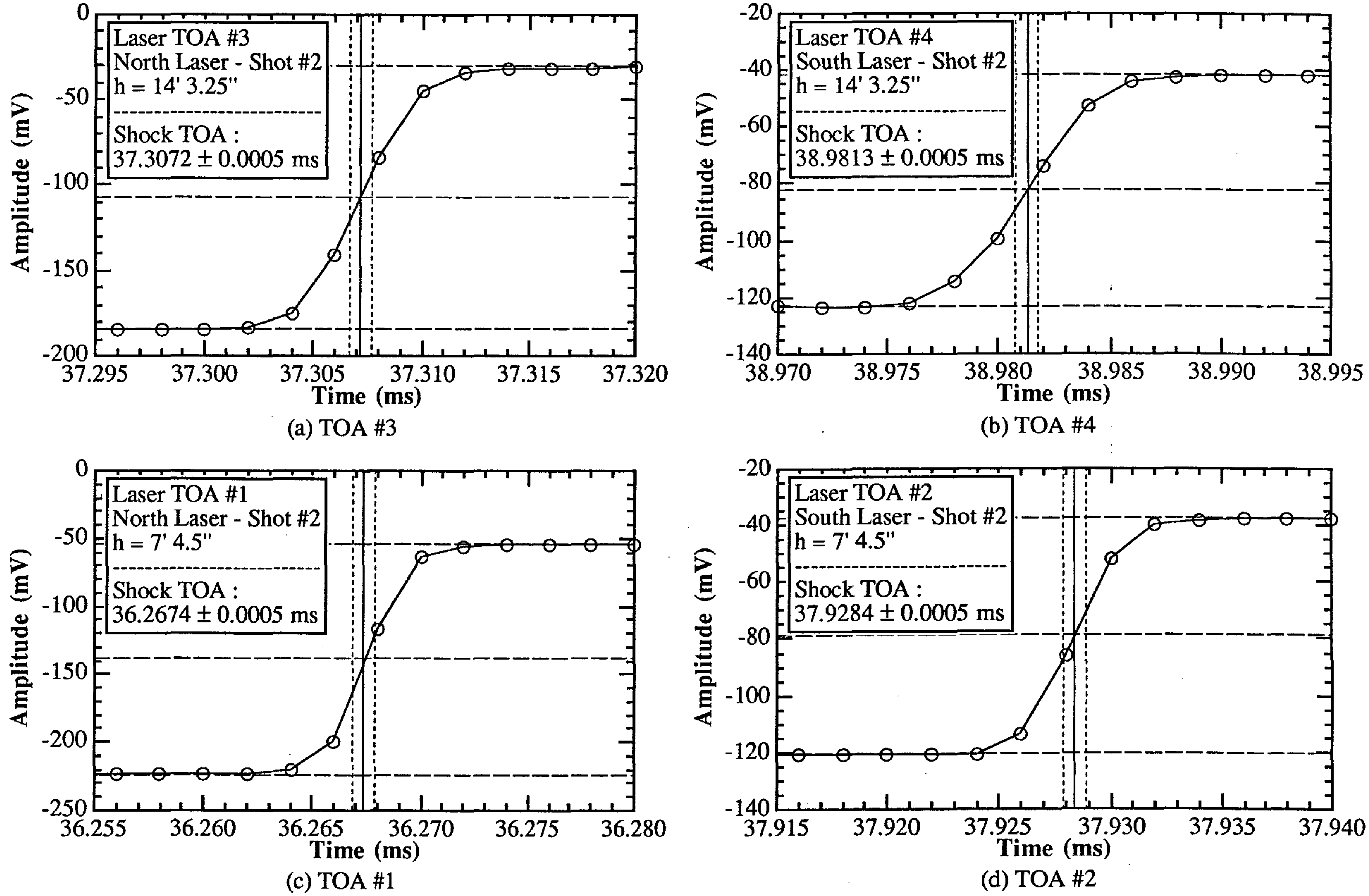


Figure 4-14. CRC laser TOA determination for LB/TS single driver Shot #2 (5/15/97).

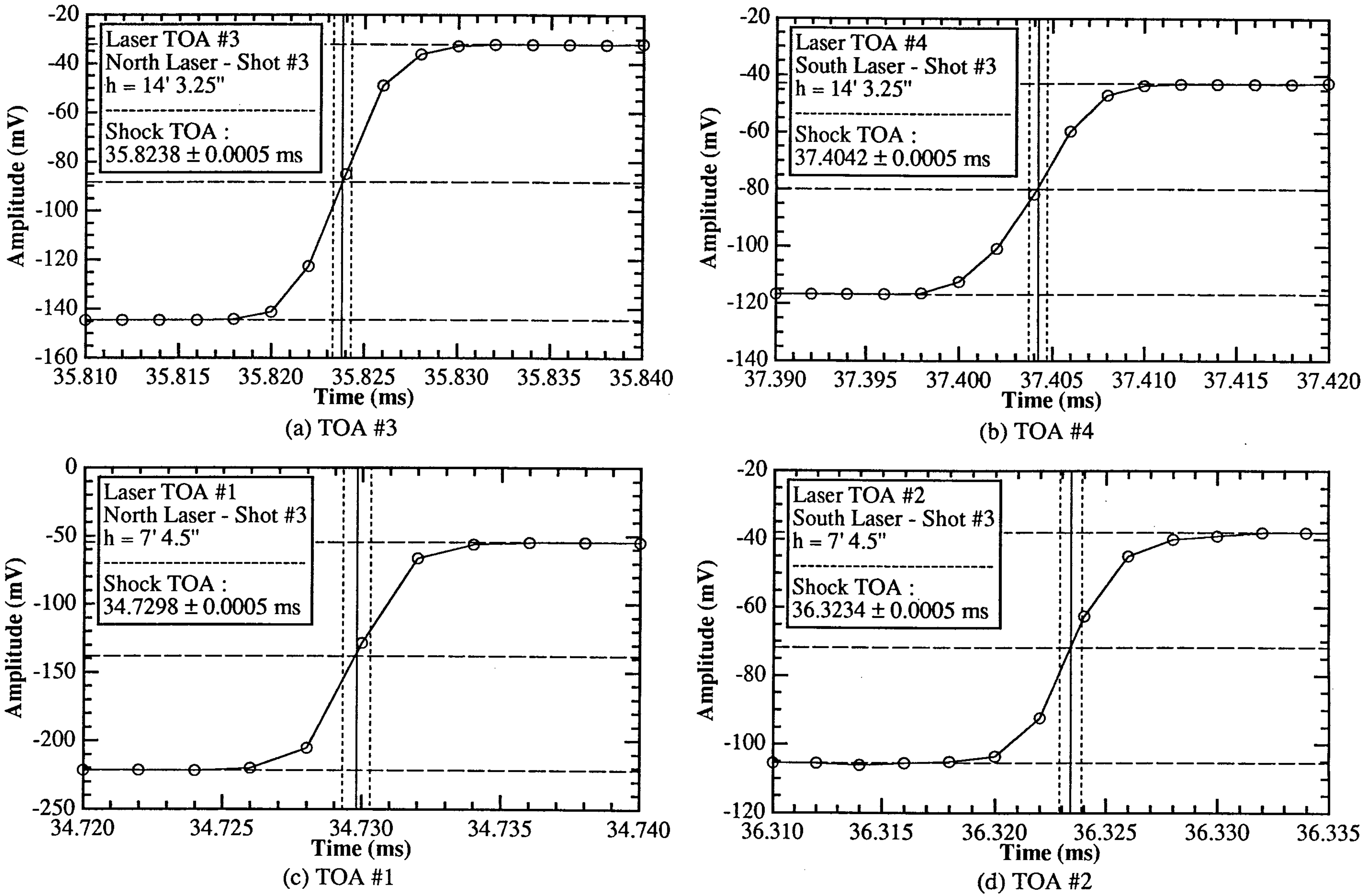


Figure 4-15. CRC laser TOA determination for LB/TS single driver Shot #3 (6/25/97).

Table 4-1. Laser beam TOA values.

Shot No. (data)	TOA 1 (ms) h = 7' 4.5"	TOA 2 (ms) h = 7' 4.5"	TOA 3 (ms) h = 14' 3.25"	TOA 4 (ms) h = 14' 3.25"
1 (3/19/97)	37.5528	39.2392	38.5968	40.3003
2 (5/15/97)	36.2674	37.9284	37.3072	38.9813
3 (6/25/97)	34.7298	36.3234	35.8238	37.4042

Since Driver #5 is near the floor of the facility one expects that for some distance down the tunnel the shockwave would be somewhat stronger at the floor than at higher elevations. The shock surface would not be just a tilted plane, but a curve convex in the direction of motion as qualitatively shown in Figure 4-16. With laser beams at only two heights one can make a reasonable estimate of the curvature of the shock front, but cannot compute the accurate contour that could be produced by a beam array such as that shown in Figure 3-1.

4.3 SHOCK OVERPRESSURE.

The shock front overpressure is computed from the knowledge of the shock's speed normal to its surface and the ambient air pressure and temperature (to get sound speed) into which it is propagating, using the Rankine-Hugoniot relations for a planar shock wave. The ambient air pressure, temperature, and soundspeed for the three shots are given in Table 4-2; the initial blast driver tube pressure, and the driver gas temperature are also given.

The shock speed parallel to the LB/TS floor was determined by dividing the distance between the tandem beams (TOA 1/TOA 2 = 24.170-in = 2.014-ft and TOA 3/TOA 4 = 24.100-in = 2.008-ft.) by the time difference in shockwave TOA between the two beams.

The overpressure results shown in Table 4-3 are the *maximum* values which can be obtained. They would be correct if the shockwave had propagated as a vertical plane. However, since we know it did not, the angle of propagation at each of the two beam elevations was estimated, giving somewhat shorter distances (than the distance between beams) that the shockwave traversed during the TOA time increment measured between the tandem beams. The overpressures computed using these new distances are presented in Table 4-4. [Obviously, laser beams installed at a third height would have been invaluable in

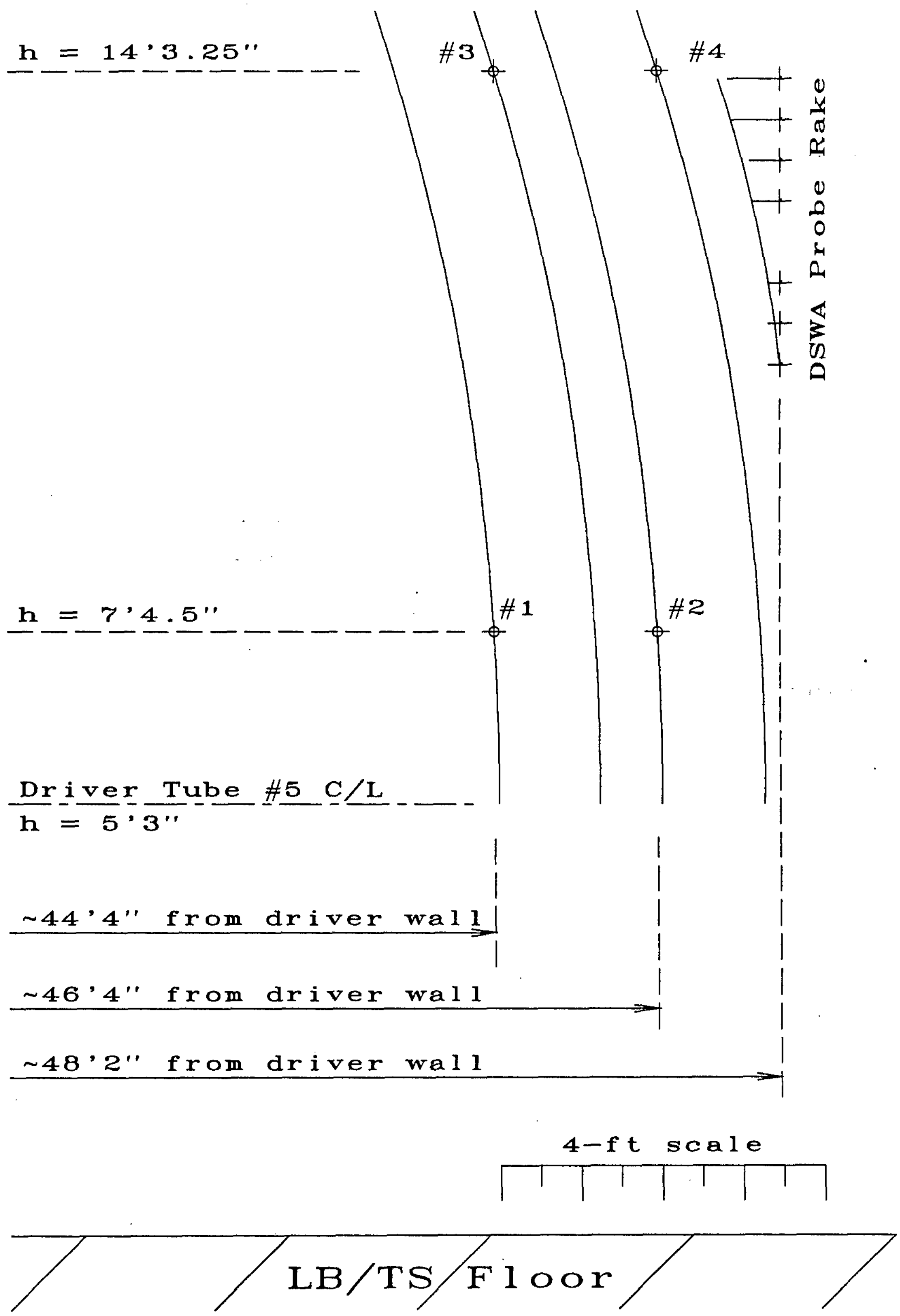


Figure 4-16. Shock profile sketch from laser TOA system and DSWA probe rake.

Table 4-2. Ambient air conditions and driver initial conditions.

Shot No. (date)	Ambient Pressure (psi)	Ambient Temperature (°F)	Sound Speed (ft/sec)	Driver Pressure (psi)	Driver Temperature (°F)
1 (3/19/97)	12.49	51	1,108.1	200.8	63.5
2 (5/15/97)	12.33	73	1,132.0	200.2	59.1
3 (6/25/97)	12.31	75	1,134.1	443.8	54.9

Table 4-3. Computed overpressure values from laser TOA measurements.

Shot # (date)	elevation = 7' 4.5"		elevation = 14' 3.25"	
	Δt @ 7' 4.5" (ms)	ΔP (psi)	Δt (ms)	ΔP (psi)
1 (3/19/97)	1.6864	2.35	1.7035	1.92
2 (5/15/97)	1.6610	2.11	1.6741	1.76
3 (6/25/97)	1.5936	3.47	1.5804	3.67

Table 4-4. Computed overpressure values corrected for shock angle.

Shot No. (date)	elevation = 7' 4.5" Δt (ms)	ΔP (psi)	elevation = 14' 3.25" Δt (ms)	ΔP (psi)
1 (3/19/97)	1.6864	1.81 - 2.30	1.7035	1.39
2 (5/15/97)	1.6610	1.59 - 2.06	1.6741	1.25
3 (6/25/97)	1.5936	2.79 - 3.45	1.5804	2.21 - 2.97

computing the shock front curvature more accurately, and from that, the slope of the wavefront and overpressure at each beam pair.]

It is noted that corrections for such curvature likely would be small or unnecessary at the facility test section, since the shock front would be virtually a vertical plane at that location.

4.4 TOA SHOCK OVERPRESSURE COMPARED WITH PRESSURE GAUGE MEASUREMENTS.

DSWA made overpressure measurements using pressure probes located on horizontal and vertical rakes just downstream of the laser beams. For Shots 1 and 2 the static pressure ports were located 36-in to 38-in downstream from a point halfway between two beam pairs; on Shot 3 that distance was 42.375-in. Over these relatively small dimensions the shock front should not have decayed a large amount between the laser measurements and the pressure probes.

Selected pressure gauge measurements are shown in Figures 4-17, 4-18, 4-19, and 4-20 for Shots 1, 2, and 3. Although the selected pressure measurement heights are about two feet lower than these of the laser beams, it is considered reasonable to compare the shock overpressures measured by each method.

Figure 4-17a shows that for Shot 1 the estimated slope of the shock front might have deviated too much from the vertical at the elevation, h = 14-ft 3.25-in; therefore, perhaps the

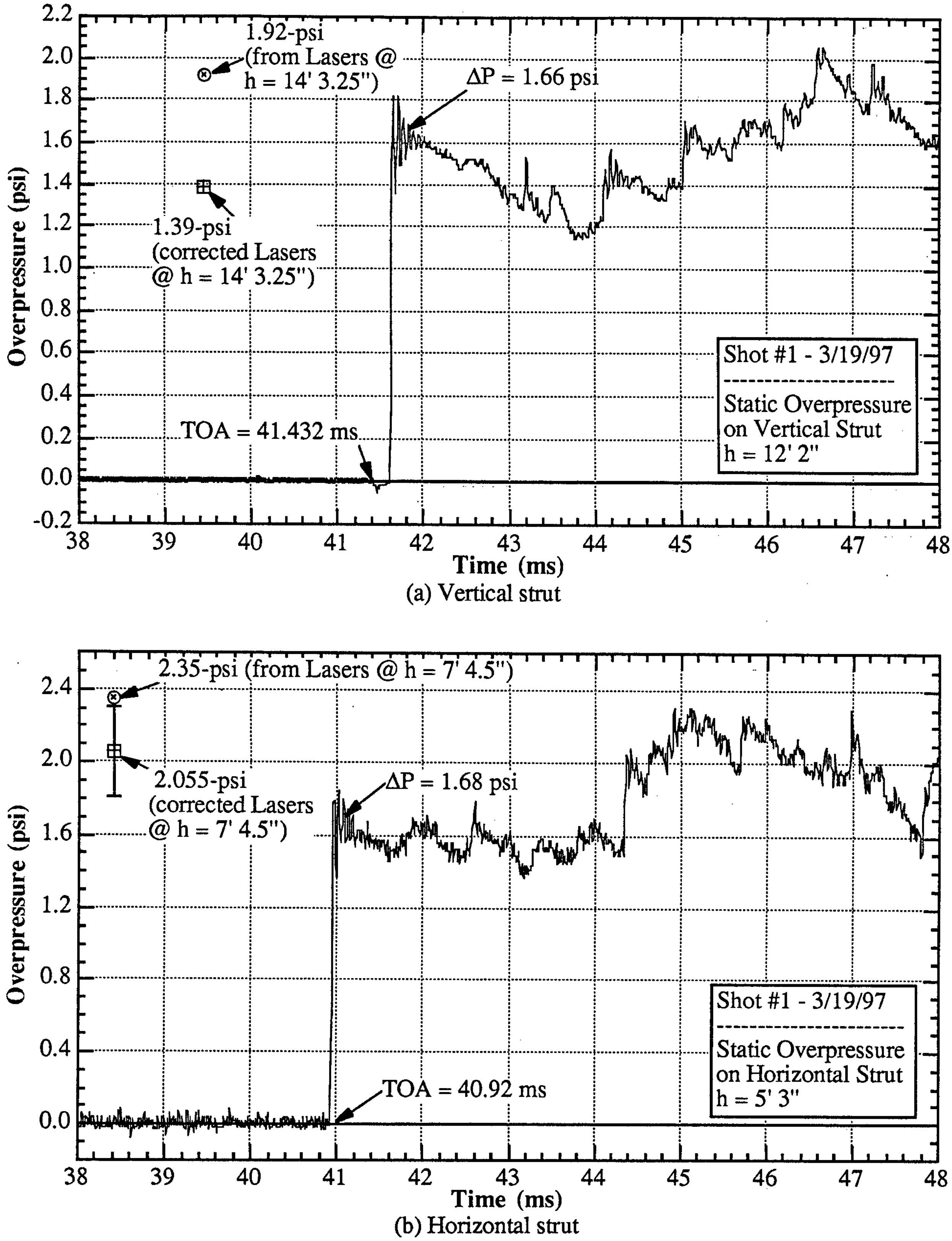
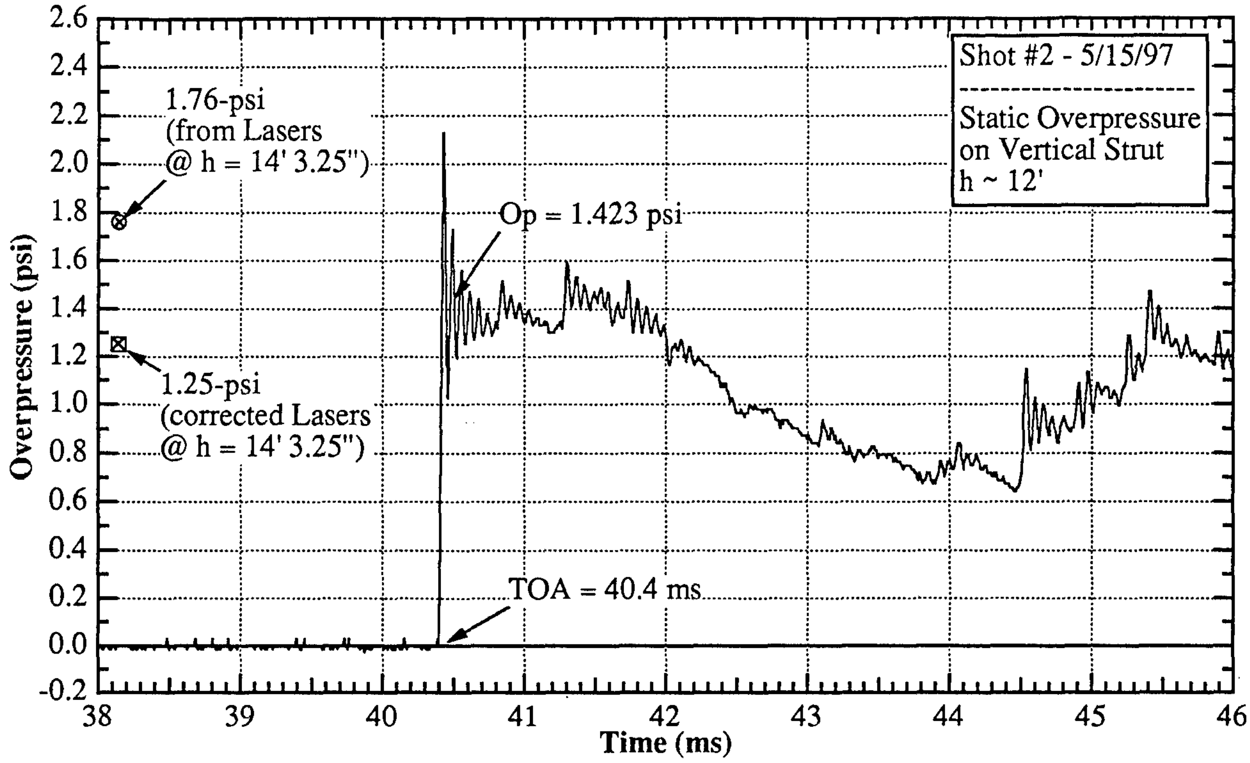
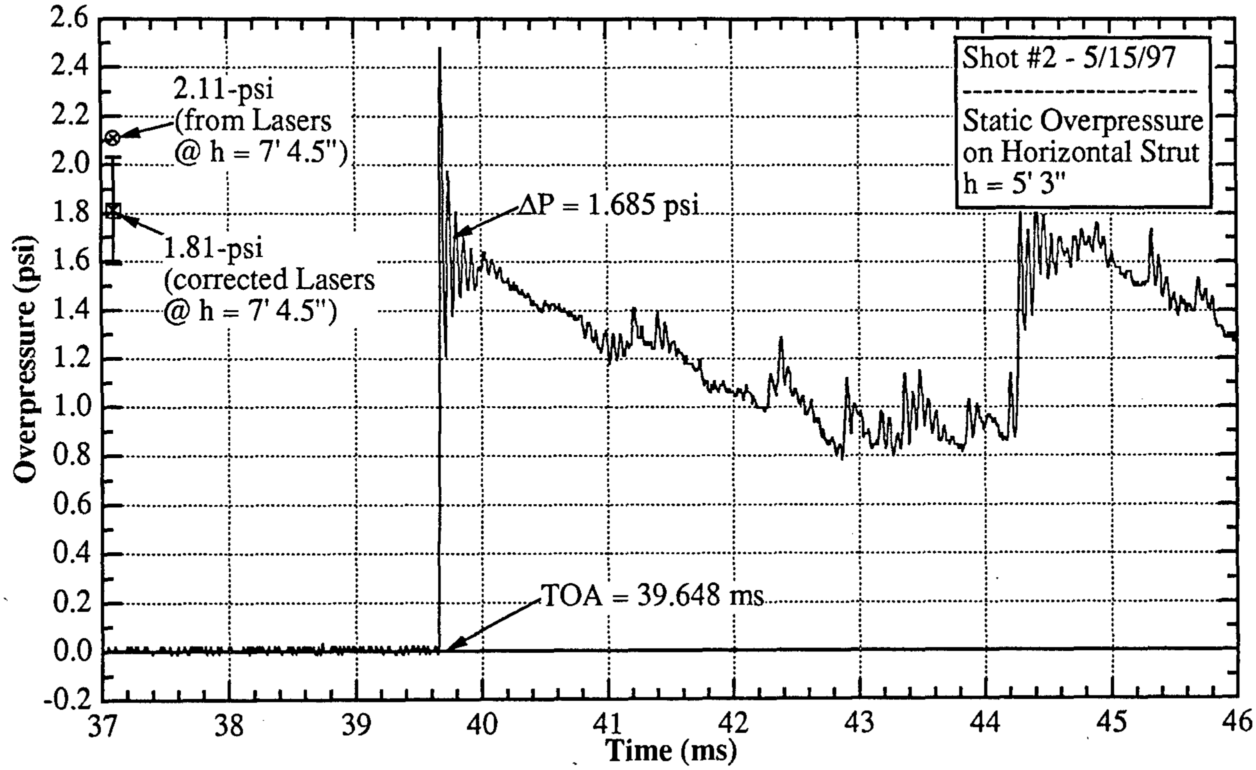


Figure 4-17. DSWA static overpressure measurements on vertical and horizontal struts of boundary layer rake; single driver Shot #1 (3/19/97).

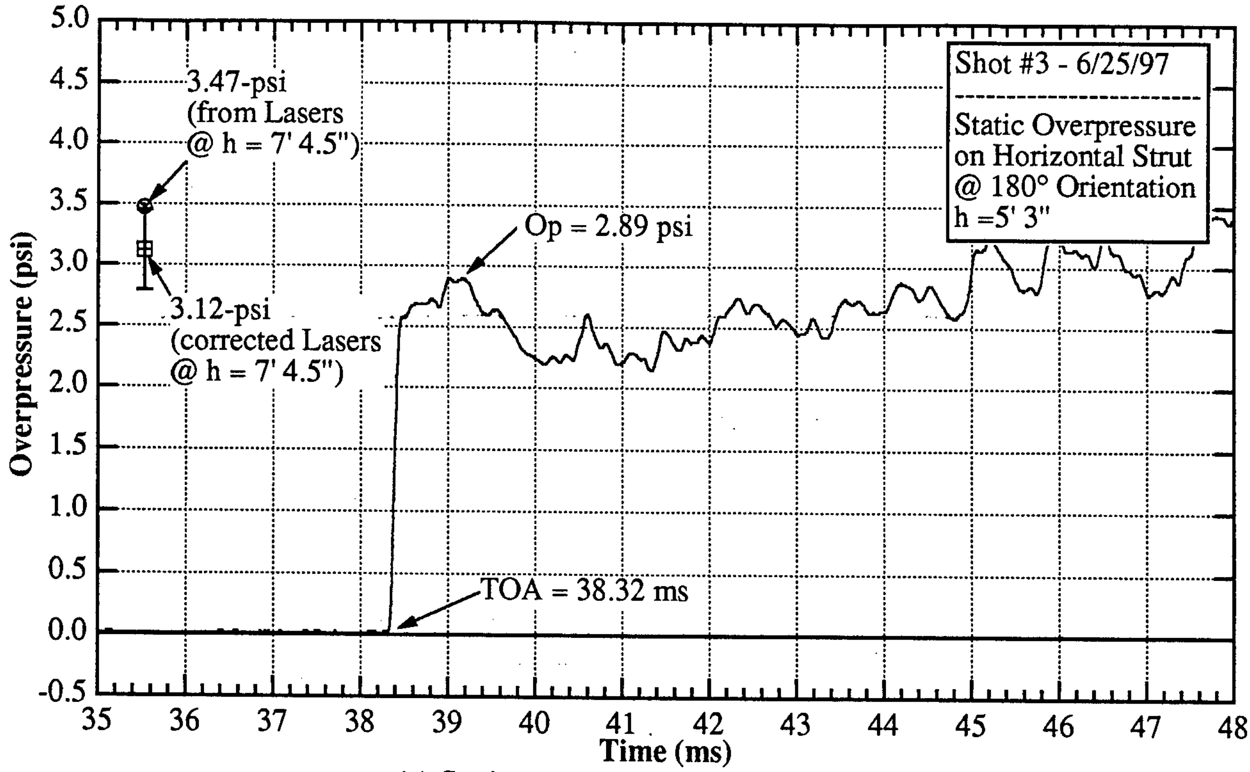


(a) Vertical strut

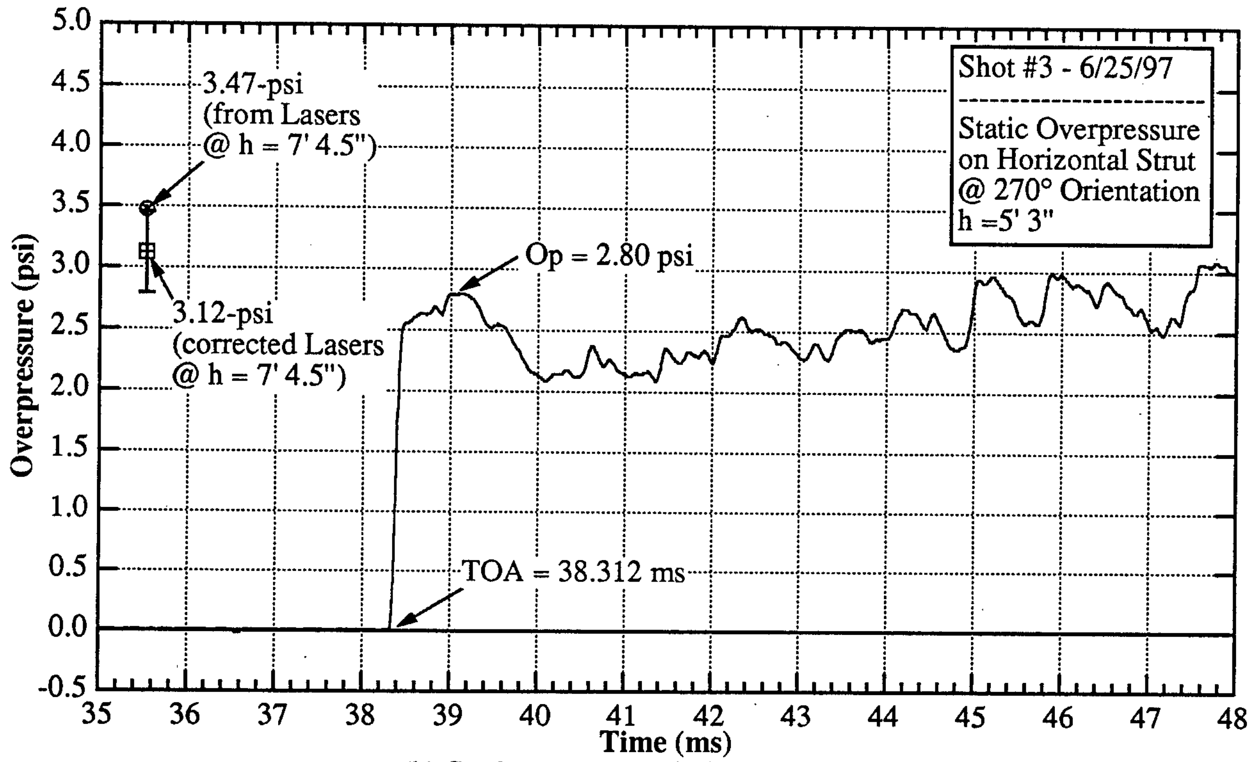


(b) Horizontal strut

Figure 4-18. DSWA static overpressure measurements on vertical and horizontal struts of boundary layer rake; single driver Shot #2 (5/15/97).

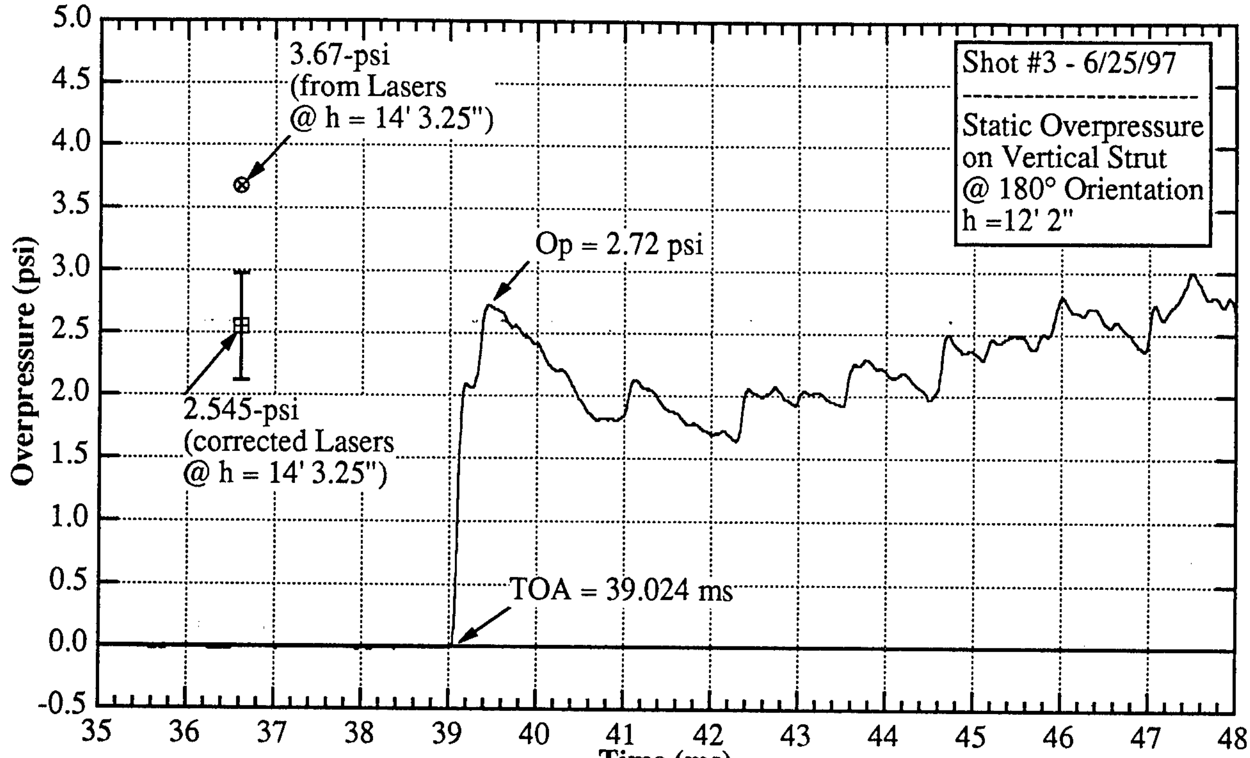


(a) Static pressure at 180° orientation

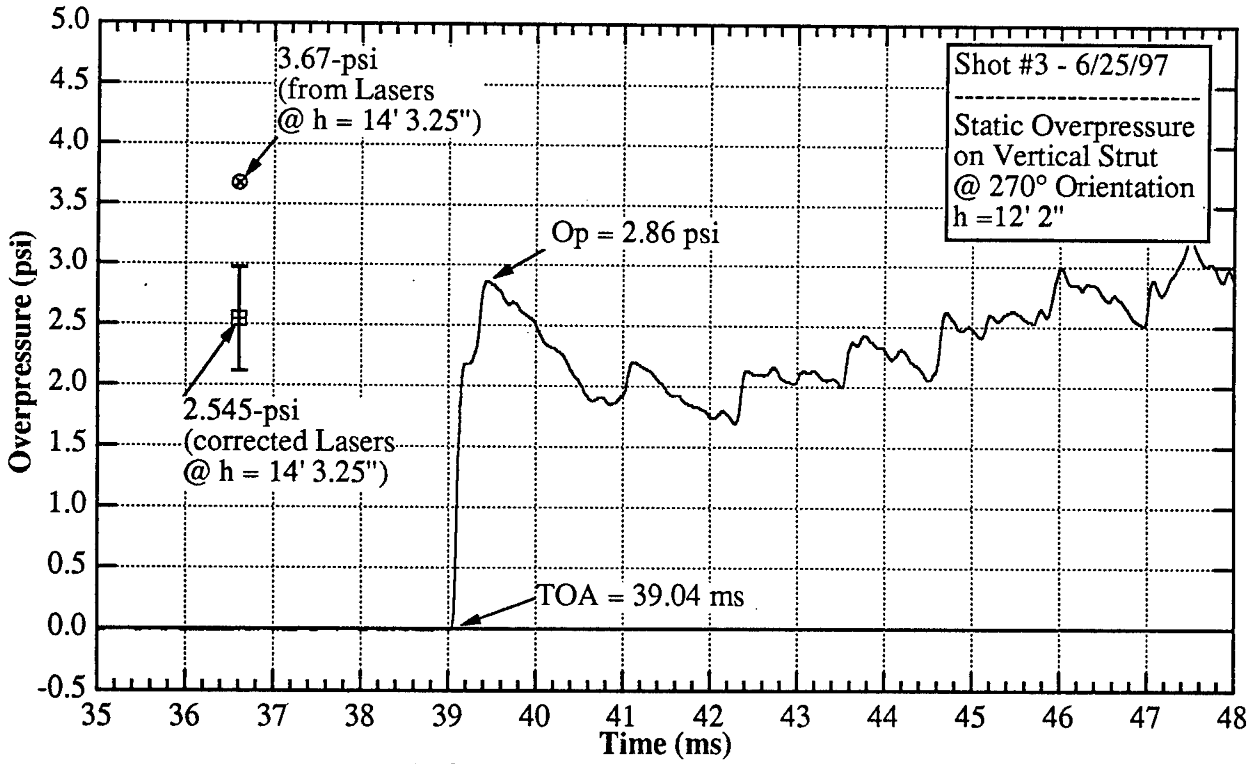


(b) Static pressure at 270° orientation

Figure 4-19. DSWA static overpressure measurements on horizontal strut of boundary layer rake; single driver Shot #3 (6/25/97).



(a) Static pressure at 180° orientation



(b) Static pressure at 270° orientation

Figure 4-20. DSWA static overpressure measurements on vertical strut of boundary layer rake; single driver Shot #3 (6/25/97).

corrected laser point is somewhat too low. However, the probe-measured over-pressure at h = 12-ft 2-in might be somewhat too high since it is virtually the same as that at 5-ft 3-in (Fig 4-17b), and it appears that the shock was actually weaker at the higher elevation, judging from the later TOA there. The bar shown about the corrected laser value shown on Figure 4-17b indicates the range of values obtained when correcting using either a curve similar to that shown in Figure 4-16 or a straight line between the lower and upper laser stations, to determine the slope of the shock front.

Figure 4-18a suggests that for Shot 2 the corrected laser overpressure is probably about right at h =14-ft 3.25-in; it is somewhat lower than the pressure probe value, as it should be if the overpressure decays with height as expected. However, Figure 4-18b suggests that the corrected laser overpressure is perhaps a little too high, since its measurement elevation is higher than that of the DSWA pressure probe.

Figure 4-19 shows that at the lower elevation for Shot 3, the corrected laser pressure is somewhat higher than the pressure probe measurement. This could, of course, be valid if the shock pressure decayed with distance as it progressed down the tunnel between the laser beams and the pressure rake. The corrected laser pressure shown in Figure 4-20 for Shot 3 at the upper elevation seem to agree rather well with the pressure probe values.

Clearly, if one is to use the laser overpressure values as a quantitative check on pressure probe measurements, the beams should "straddle" in space the pressure probe sensing port. Also, a cluster of three laser beams should be used so that the slope of the shock front at the station can be accurately determined.

SECTION 5

CONCLUSIONS

1. The laser beam interruption method is a reliable and accurate way to measure air shock TOA, requiring little maintenance and pretest preparation once the system is set-up.

2. When the angle of the incident shockwave is known relative to a pair of laser beams, the shock overpressure can be determined quite accurately from the shock velocity obtained by the beams and a knowledge of the ambient conditions (pressure and temperature/soundspeed) of the unshocked air.

3. When there is considerable curvature in the shock front, three or more laser beam stations are required in the direction of shock curvature in order to determine the shock angle and shock overpressure correctly. Such strong curvature is present relatively near (~14 m) the driver tubes in LB/TS. As the blast wave propagates farther down the tunnel, the curvature of the shock front should decrease, thereby minimizing the number of laser beams required in the array for obtaining shock overpressure with high accuracy.

4. Properly installed with Epoxy, the laser and collector optics boxes can be firmly anchored to a concrete wall to withstand blast loads without requiring special aerodynamic fairing.

5. The concrete walls of the LB/TS are quite stable for at least the 14-m station, as shot by the virtually motionless laser beam paths before, during (behind the shock), and following the blast passage and for a period of months.

SECTION 6

RECOMMENDATIONS

1. When an accurate knowledge of the shock front TOA, curvature, and shock overpressure are desired at the LB/TS test section over a substantial test area without pressure gauges or rakes present in the flow, an array of laser beams is recommended.

2. When a check on the shock measurement accuracy of a key static pressure probe measurement or stagnation pressure measurement is desired in the LB/TS tunnel, a simple array of three laser beams should be considered with the beams located such that they straddle the pressure probe location. Such an arrangement would provide a high-confidence check each time a shot is made with little preparation required, and could serve as a backup to the pressure probe should that measurement be questionable or lost.

APPENDIX

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ampere	A
bar	-
calorie	cal
per gram	cal/g
center line	C/L
Chapman-Jouget	C-J
degree	
Celsius	°C
Fahrenheit	°F
Kelvin	K
detonation energy	E
diameter	dia
divisions	div
foot (feet)	ft
per second	ft/s
gram	-
per cubic centimeter	g/cm^3
height of burst	HOB
hertz	Hz
inch	in
per second	in/s
kilo (10^6)	
bar	kbar
calorie	kcal
hertz	kHz
ohm	kΩ
ton (yield)	KT
volts	kV
mega (10^6)	
hertz	MHz
meter	m
per second	m/s
micro (10^{-6})	
farad	μF
second	μs
milli (10^{-3})	
meter	mm
second	ms
volt	mV
nano (10^{-9})	
meter	nm
ounce	oz
pico (10^{-12})	
farad	pF
pounds	lb
per square inch	psi
per square inch (absolute)	psia
per square inch - second	psi-s
overpressure	ΔP
sea level	S.L.
seconds	s
time of arrival	TOA
volt	V

Atmospheric Conditions

standard atmospheric pressure at S.L.	$p_o \equiv 14.696$ psi
standard atmospheric temperature at S.L.	$T_o \equiv 288$ K

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